TRANSACTIONS

of the

American Society for Steel Treating

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CLEVELAND—THE CONVENTION CITY

AN aggressive civic step which has attracted world-wide attention to Cleveland is the Group Plan for public buildings. A "T" shaped tract of land approximating 104 acres in the heart of the city and known as the "Mall," will ultimately contain all of Cleveland's municipal buildings. The Federal Building, costing

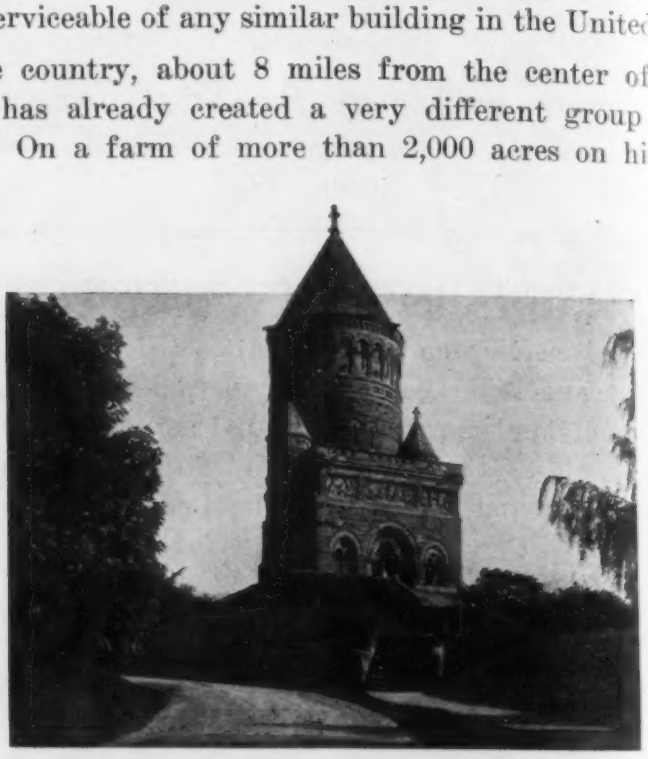
Cuyahoga County Court-House

$3,870,000, the Cuyahoga County Court House, costing $4,500,000, and the City Hall, costing $3,330,000, are already occupied. Appropriations are outstanding for a Criminal Court building upon the "Mall." The new Public Library has just been completed. The entire project will represent an outlay in excess of $35,000,000.

The Public Auditorium, opened in the spring of 1922, also located on the "Mall," constitutes another unit of the "Group Plan." The auditorium accommodates 12,500 persons, while upwards of 70,000 square feet of floor space is available for exhibits.

The acoustics of this mammoth auditorium have proven ideal. Exhibit engineers have proclaimed its exhibit facilities to be the finest and most serviceable of any similar building in the United States.

In the country, about 8 miles from the center of the city, Cleveland has already created a very different group of public buildings. On a farm of more than 2,000 acres on high land a



Garfield Monument

fine sanitarium for tubercular patients, a home for aged and infirm, with cottages where old couples can spend their last years together, and all the necessary buildings to make such a city farm complete, stand as a monument to the generosity and kindliness of the people of Cleveland. Upon the same tract of land is the municipal house of correction, with ample fields about it for outdoor work and shops for winter employment.

Cleveland, as the center of the Western Reserve, has many points of interest of national importance. As the home of many of the country's great men, both politically and industrially, the eyes of the nation have always been upon Cleveland.

This was the home of James A. Garfield, at one time President of the United States. The Garfield Monument, built by national subscription, is one of the famous memorials of the country. The residence of John Hay, Secretary of State under McKinley, was in Cleveland. His burial place is in Lake View Cemetery. Tom L.

Johnson, nationally known as the Father of Three-Cent Street Car Fare, was Mayor of Cleveland for several terms. Marcus A. Hanna, at one time United States Senator and national figure, resided in Cleveland, and a massive monument has been erected to his memory. John D. Rockefeller, oil king and philanthropist laid the foundation of his fortune and spent the greater part of his life

The Rose Garden in Wade Park

in Cleveland, and his estate here is one of the show places of the city. Cleveland is also the home of Newton D. Baker, former secretary of War.

There are practically no areas of congested population in Cleveland, as the city is noted for the great number of home owners. According to the 1910 Federal census, 35 per cent of Cleveland homes were owned by the occupants, being second of the American cities in this respect.

The city's education facilities are notable. In the city system are 110 grade schools, twelve high schools of which three are technical high schools and nine junior high schools. Parochial schools number fifty-seven.

Cleveland is the seat of Case School of Applied Science, Western Reserve University (including the College for Women), and of St. Ignatius College. Case offers courses in civil, mechanical, electrical, mining, metallurgical and chemical engineering and physics. Western Reserve has in addition to Adelbert College, Schools of Medicine, Law, Dentistry, and Pharmacy, and courses

in Education and Applied Social Science. St. Ignatius confers baccalaureate degrees and gives courses in philosophy, language, literature, history, science and mathematics.

Following the Cleveland principle of making community enterprises really serve the community, the Public Library, which is a part of the "Group Plan," has forty-six branches and 590

Cleveland Museum of Art

distributors. In gross circulation of books, the Fifth City ranks third in the United States and in per capita circulation first.

Visitors reaching Cleveland by railroad are deeply impressed at the magnitude of the city's manufacturing districts, through the miles upon miles of factory fronting upon the railroads. But upon reaching the downtown mercantile district the visitor is at once filled with awe at the activity and splendor which meets the eye from all sides. This is especially true of Euclid Ave., the principal retail mercantile street, famous the world over.

The Cleveland Museum of Art is regarded as one of the most beautiful museum buildings in America. It has no superior in the perfection of equipment for handling and preserving its treasures. In addition, it serves a valuable purpose in the educational life of the city. Being linked so closely with the city's schools and colleges, it has become an essential factor in their work as well as a center of culture for the whole community.

Its treasures have been selected for their high quality rather than quantity. While the collections are small compared with

those in some of the great museums of the world they are made up of the finest objects procurable, chosen with definite regard for their educational value.

Probably no other one agency has served to carry the story of Cleveland's educational and cultural progress to the outside world more than the Cleveland Symphony Orchestra, proclaimed one of the best in America. Organized in 1919 under charter of the Musical Arts Association of Cleveland, this orchestra has played in fourteen states and in many Canadian cities. It has been honored by many invitations to play abroad.

The public library system of Cleveland is one of its outstanding educational features. Recently a new building was erected at a cost of $4,000,000 and forms a part of Cleveland's Mall, or group plan of public buildings. Situated in the heart of the business section it is unusually accessible to all citizens and visitors. This building provides space for more than 2,000,000 volumes. From this as a nucleus, the library system extends to 945 branches in all parts of the city. Even industrial plants are equipped with libraries as a part of this system. These branches are really community centers and their service is invaluable. The system has more than 200,000 patrons each year.

Probably nowhere outside of New York City is there a more magnificant shopping district than in Cleveland. Wide streets accomodate the tremendous vehicular traffic and broad sidewalks permit the rapid passage of the hundreds of thousands who throng this district daily.

But above all, is the remarkable transformation which has occurred in this district during the past few years. Business houses have spread out over a larger area and have moved eastward along Euclid Ave. and adjacent thoroughfares; magnificent buildings have been erected; the very latest of designs in store architecture have been followed; store windows so attractive that they compel the passerby to tarry and view their artistic displays, exhibit the latest styles and creations of this country and of Europe.

In Cleveland today are many of the finest retail stores and restaurants in the United States. Merchants, as though spurred by the incentive that wide streets and sidewalks and magnificent buildings offer, have striven to outdo one another in making their establishments attain perfection in beauty and artistic decoration. This

thought is unconsciously conveyed to the visitor and the result is that Cleveland's shopping district has become nationally famous.

The same idea has been carried out by theatrical enterprises and in 1920 seven elaborate playhouses were erected augmenting Cleveland's previously ample facilities for the amusement of theatre

Playhouse Square

lovers. These playhouses, for the drama, vaudeville and motion pictures; are the last word in architectural design. B. F. Keith's new Palace Theatre has been pronounced the finest in the world. Four of the new theatres are located in the upper section of Euclid Ave. recently occupied by mercantile establishments. These theaters, which alone provide more than 11,000 seats, are within the same block now known as "Playhouse Square."

After a busy day in the manufacturing districts or at convention sessions, the visitor to Cleveland may easily find restful pleasures to occupy the evening hours, for notwithstanding the city's phenomenal growth in population and industry, its facilities for healthful pursuits and wholesome recreation have kept pace.

LARGE FORGINGS

MUCH interest and attention has been directed by heat treaters and metallurgists to the increasing demand for large forgings and to the increasing size of these units. The production and heat treatment of large forgings is quite a different matter from the production of small sized steel forgings which are used in such vast quantities in the automotive and similar industries today.

In this issue of TRANSACTIONS is published a capable presentation of this subject by a writer who has much experience in the production of these large units. The author, A. O. Schaefer, presents in an interesting manner the many problems which are met with in the production of suitable ingots; the precautions which must be taken in pouring, heating, forging, heat treatment and testing. This author has stressed the point of the necessity for producing sound ingots and the necessity for allowing ample time for these large masses of material to become thoroughly heated through at the proper temperatures before any forging work is done upon them.

With the increasing demand for high pressure steam installations and with increasing developments in the field of chemical technology, the production of these large forgings will increase and will become a stable peace time industry where formerly such large units were usually instruments of war.

VOLUME VII OF TRANSACTIONS COMPLETED

THIS issue of TRANSACTIONS completes Volume VII, which covers the period from January, 1925, through June, 1925. Volume VIII will include the period from July, 1925, through December, 1925. The index for Volume VII is now ready and may be secured upon request.

Those desiring to have their loose copies of Volume VII bound in accordance with the style used in binding Volumes I, II, III, IV, V and VI, may do so by forwarding them to the executive offices of the Society, 4600 Prospect Avenue, Cleveland, together with $2.00, and they will be bound and returned promptly.

REPORT OF SUB-COMMITTEE ON SPRING STEELS

THE Recommended Practice Committee assigned to the Sub-committee on Spring Steels the problem of compiling a recommended practice for the heat treatment of plain carbon and alloy spring steels.

This sub-committee has put much effort into this problem, and recently submitted to the Recommended Practice Committee its report which was approved as a tentative recommended practice of the Society.

The Sub-committee on Spring Steel is composed of four users and three manufacturers as follows: Users: W. H. Phillips, chairman, DuRay Smith, C. G. Shontz and H. G. Peebles. Manufacturers: E. C. Smith, J. W. Weitzenkorn and Elmer Larned.

This recommended practice covers primarily the heat treatment of medium and large size coil springs and flat leaf springs.

Recommended Practice for the Heat Treatment of Plain Carbon and Alloy Spring Steel

General

THIS recommended practice covers the process to be followed in the manufacture and heat treatment of springs, such as medium and large coil, and flat leaf springs.

Process of Manufacture

Spring steels are manufactured largely by the open hearth process. A considerable quantity is produced by the electric furnace and a small amount by the crucible process.

Spring Steels and Their Chemical Composition

The steels listed below are those most commonly used by the spring manufacturers.

Approximate Chemical Composition

Steel	C	Mn	P	S	Si	Cr	V	Mo
C	0.90–1.05	0.30–0.50	0.040	0.050	0.10–0.25	.....	.....	.....
Cr	0.45–0.55	0.80–1.00	0.040	0.050	0.10–0.20	1.00–1.20	.....	.....
Cr-V	0.45–0.55	0.70–0.90	0.040	0.050	0.10–0.20	1.00–1.20	0.15–0.25	.....
Cr-Mo	0.45–0.55	0.70–0.90	0.040	0.050	0.10–0.20	0.70–0.90	.....	0.20–0.30
Cr-Si-Mn	0.45–0.55	0.70–0.90	0.040	0.050	0.40–0.60	0.70–0.90	.....	.....
Si-Mn	0.55–0.65	0.70–0.90	0.045	0.050	1.80–2.10	.....	.....	.....

Hardness of Steel as Received from Manufacturer

(a) The maximum hardness limit of leaf spring steel will depend to a considerable extent upon the nature of any cold work to be performed upon it. A maximum Brinell hardness number of 321 is satisfactory for the thinner gages (less than $\frac{5}{16}$ inch) where only the simple cold working operations such as shearing, punching, and trimming are necessary. Heavier gages ($\frac{5}{16}$ inch or over) should have a maximum Brinell hardness number of 302. A minimum hardness limit is necessary only in special cases.

(b) All coil spring bars ½ inch and under should be soft enough to permit shearing without breaking. Larger sizes should be purchased cut to the proper lengths.

Forging, Forming, and Coiling

The lowest temperature at which the steel will work satisfactorily should be used. This temperature should not exceed 1850 degrees Fahr., and the steel should be held at this temperature for only sufficient time to thoroughly soak through.

The method of cooling after forging or forming is usually not important. When severe coiling or other severe forming operations are performed, the steel should be allowed to cool in the air until it becomes black.

Heat Treatment of Spring Steel

Normalizing

The steel is normalized when considerable machining is required, when severe cold working is to be done, or when the product has been subjected to localized heating at several places for the purpose of forging. The normalizing temperatures are given in Table I.

Hardening

The steel should be heated uniformly to the temperature shown in Table I and quenched in oil. The time, in minutes, of

heating in the furnace may be determined approximately by multiplying the diameter or thickness of the steel in inches by 60.

Tempering

The steel should be heated in a suitable tempering medium to the temperature shown in Table I. It should be held at this

Table I
Heat Treatments for Leaf and Coil Springs

Steel	Normalizing Temperature Degrees Fahr.	Hardening Temperature Degrees Fahr.	Approximate Tempering Temperature* Degrees Fahr.	Brinell Hardness Number
C	1575–1625	1525	600–950	352–415
Cr	1600–1650	1525	650–950	363–444
Cr-V	1600–1675	1550–1600	675–975	363–444
Cr-Mo	1600–1675	1550–1600	675–975	363–444
Cr-Si-Mn	1600–1650	1600–1650	675–975	363–444
Si-Mn	1600–1650	1600–1650	650–950	363–444

*The tempering temperatures are to be used only as a guide in obtaining the Brinell hardness numbers given in the table.

temperature for sufficient time to permit complete penetration of the heat. The method of cooling after tempering is optional.

Hardness Testing of Finished Product

The Brinell test is widely used on flat leaf springs, and when specified should conform to the limits shown in Table I.

Hardness tests on helical springs may be made by the Brinell, Rockwell, or scleroscope tests. When the Brinell is specified, it should conform to the limits shown in Table I.

SPRING SECTIONAL MEETING

THE report of the Spring Sectional of the Society held in Schenectady, New York, May 28, 29 and 30, 1925, will appear in the July issue of Transactions.

THE MANUFACTURE AND HEAT TREATMENT OF LARGE FORGINGS

By A. O. Schaefer

Abstract

The manufacture of large heat treated forgings is discussed in this paper. The author has discussed melting practice, ingot mold design, various methods of pouring, hot tops, etc. The heating and forging of large ingots is discussed in detail. Photographs of a number of large forgings under various stages of production are included. Most of the large forgings are produced on hydraulic presses, inasmuch as steam hammers are not suitable for the forging of heavy sections. The steam hammer has the tendency to work only the surface of the mass of metal, whereas the hydraulic press, working much slower, exerts its effect throughout the section which is under the dies of the press.

The heat treatment and testing of forgings is given much consideration. The necessity of the proper rate of heating and soaking at heat of large forgings is emphasized by the author. The testing and inspection of finished forgings are likewise discussed in some detail.

THIS paper is presented in an endeavor to indicate some of the procedures and precautions necessary in the manufacture of large steel forgings, as distinct from those of ordinary size. No attempt is made to offer a thorough account of modern forging practice.

It may safely be said that the art of forging large masses of metal was developed in the production of guns, projectiles, armor plate and engine parts for naval vessels. The second important impetus was furnished by the improvement and growing use of large steam turbine units. The demand for large forged parts for other purposes has been comparatively slight until recent years. Engineers now, however, are calling not only for larger and larger masses of forged steel, but also for large forgings of special properties. The utmost skill is demanded of the steel maker and forging master to keep pace with engineering progress.

A paper presented before the Spring Sectional Meeting of the Society, Schenectady, May 28, 29, and 30, 1925. The author, Adolph O. Schaefer, member A. S. S. T., is assistant engineer of tests, the Midvale Co., Nicetown, Philadelphia.

Melting

The successful manufacture of large forgings depends on special open hearth practice. Both acid and basic open hearth metal may be used. The first essential is the production of a sound ingot. For this purpose, a well-conditioned and deoxidized heat must be teemed at the proper temperature into an ingot mold of suitable design.

Too high a pouring temperature results in an excessively coarse crystal structure, because the large mass cools slowly through the solidification period. Such a structure necessitates extreme care in reheating and forging to prevent pulls and tears. Segregation also (particularly of carbon, phosphorus, and sulphur) is encouraged by hot pouring and the subsequent long period before solidification. Excessively segregated metal cannot subsequently be corrected, and must be cut from the forging as scrap. All other conditions being the same, a heat which is thoroughly deoxidized will not show as much segregation as one which is not. The metal will lie much more quietly in the mold, large "land-locking" crystals will grow in from the chill surface enclosing portions of the still liquid metal, preventing excessive rejection of the lower melting constituents to the center of the ingot.

The best large ingots are cast in cast iron molds similar to the one shown in Fig. 1. They may be either top or bottom poured. Each method has its peculiar advantages and disadvantages. Top pouring is simpler, but the splash into the mold tends to produce poor surfaces. Drops splash from the stool onto the walls of the mold, solidify, and may cause "scabs" or laps on the surface of the ingot. Bottom pouring is not open to these criticisms, but the equipment required is much more elaborate, and there is the possibility that the molten metal will erode away portions of the runner bricks and these pieces of refractory may appear later in the steel.

All ingots are poured with a sinkhead or hot top which should be of such size and design that the pipe will be confined to it, and not extend into the body of the ingot. Some hot metal is fed into the top after the mold is filled for the purpose of insuring the feeding of the shrinkage cavity with molten metal. After the sinkhead is poured, insulating material is put on the top to prevent

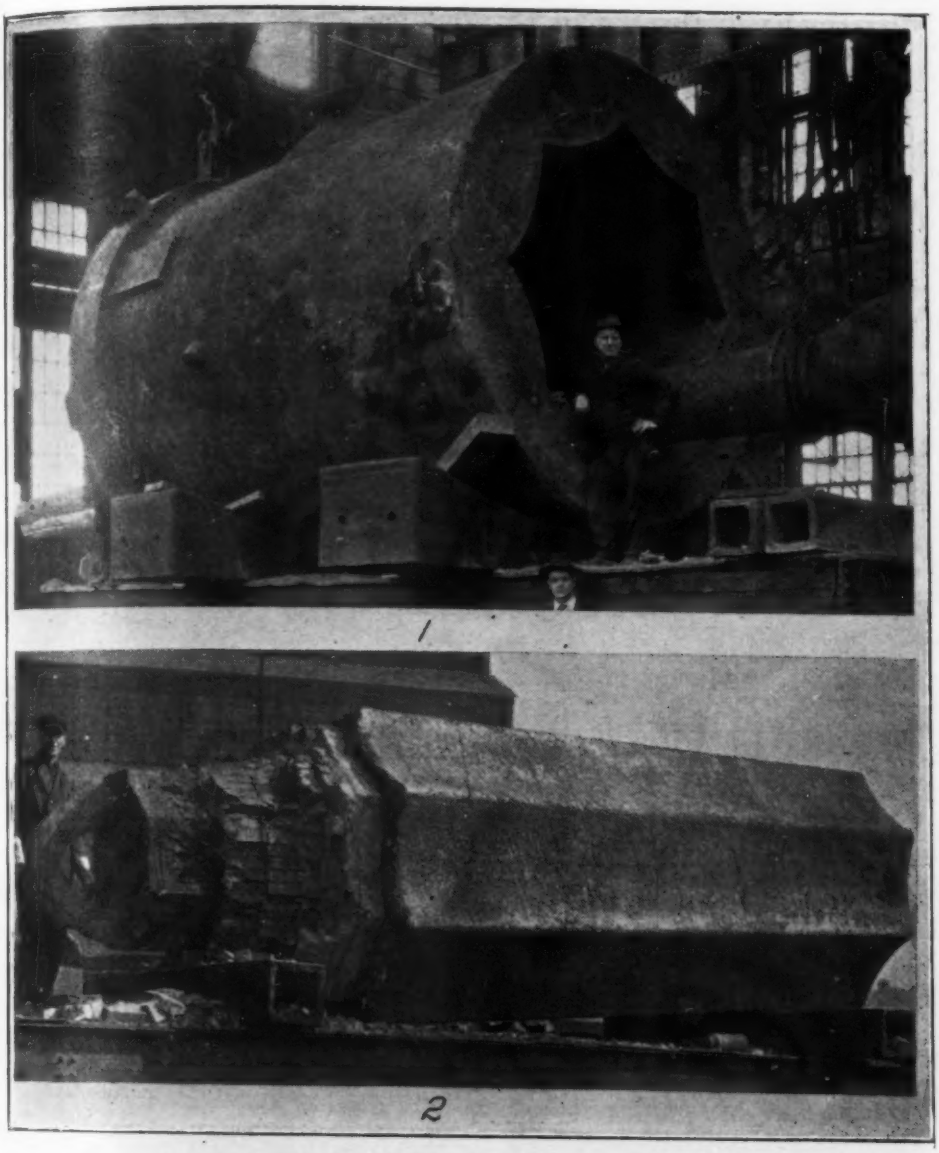


Fig. 1—Cast Iron Ingot Mold for an 83-Inch "Octagon" Ingot. Fig. 2—Typical 63-Inch "Octagon" Ingot.

too rapid solidification of this portion of the metal. Sometimes, if the sinkhead is of insufficient size or poorly designed, or the chill is too severe at the top of the body of the ingot, a bridge of metal may solidify across the ingot and prevent molten metal from feeding the ingot body. This condition may very well remain undetected when the top scrap is cut. Besides the principal shrinkage cavity, commonly called "pipe," which should be confined to

the sinkhead, there may be other shrinkage cavities or voids in various parts of the ingot. Openings due to shrinkage other than the "pipe" are called "secondary shrinkage cavities."

The ingot mold shown in Fig. 1 is typical in design for ingots for the largest forgings. It should be remembered that a particular forging can best be made from an ingot of certain cross-sectional area, the length depending on the weight needed. The mold shown is for a so-called "83-inch octagon" ingot. The "polyhedral" form is generally used in order to get the proper relation of perimeter to area of the cross section to take care of the shrinkage strains produced on solidification. A circular ingot would decrease the number of necessary forging operations, but it is more difficult to prevent cracking in an ingot of this cross section. Square or rectangular ingots, however, are sometimes used. Rectangular ingots weighing 485,000 pounds, and octagon ingots weighing as much as 275,000 pounds have been made. A typical "63-inch octagon" ingot is shown in Fig. 2.

The taper of the mold should be designed to insure easy stripping of the ingot, and the proper chill during solidification at all points, to bring the pipe up into the sinkhead. Sharp corners should always be avoided.

The attempt has been made at several times to cast cored ingots, to be used to make hollow forgings. A cored ingot would result in a great saving of metal, and a saving of time and labor. These attempts have not been entirely successful on account of the strains set up in the metal by the rigid core and the difficulty in feeding the body of the ingot.

Large ingots are also commonly cast in sand molds. These cool slowly, and minimize the danger of shrinkage strains. The slow rate of cooling, however, results in large crystal size and increased segregation.

Forging

The ingot is allowed to solidify before stripping, and is then usually charged hot into the forging furnace. It is unwise to allow a large mass of metal of such coarse crystalline structure as that existing in the ingot, containing all the stresses and strains set up by solidification, to cool too rapidly. If the ingot is not to be forged immediately, it is best to cool it in an annealing furnace

Fig. 3—A 10,000 Ton Hydraulic Press Forging a High Pressure Boiler Drum on the Finishing Mandrel.

after stripping, so that the cooling may be slow and uniform. Ingots of certain compositions are annealed.

Heating for forging is most conveniently performed in a car-bottom furnace in the case of the largest ingots. Any fuel may be used, but the action of the flame should be reducing, as the

heating period for large masses is necessarily long, otherwise a large amount of scale will be produced. For the same reason, the flame should be well baffled, and not impinge upon the surface of the ingot. Large masses of metal must be heated slowly and uniformly, and soaked thoroughly until the mass has become of uniform temperature. A "63-inch octagon" ingot is brought up to forging temperature in not less than 60 hours, depending on the initial temperatures of ingot and furnace, and soaked at heat at least 24 hours before forging.

While it cannot be said that all large forgings are made under the press, it is true that the largest forgings are pressed rather than hammered. Fig. 3 gives a general view of a modern 10,000-ton press.

The design of forging presses has changed little since their inception. They consist primarily of two dies, one movable and one fixed, with suitable apparatus for applying pressure to the movable die. In one of the earliest types the lower die was the movable, but this was soon changed so that the weight of the forging would not have to be lifted with each stroke. Improvements have been made, chiefly along the lines of removing as many valves and joints as possible from the apparatus, substituting forgings for castings in its construction, and especially in improving the handling devices. The water under high pressure may be furnished directly to the press cylinder by either one of two methods. It may be stored in an accumulator under a weighted piston, in which case the press is known as a "continuous" press, or it may be furnished directly from a steam or hydraulic intensifier. In the latter case the press is known as "intermittent." Either one or both of these principles may be applied in the design.

The steam hammer is used for forgings of comparatively small cross-sectional area. The effect of the hammer blow is sharp and effective in breaking up the crystalline structure of the steel beneath it. It is so momentary, however, that it cannot be used in working large masses or metal.

Large presses are necessary to forge successfully large masses of metal. The press must exert enough pressure to work the metal to the center of its mass.

The correct forging temperature depends upon the composi-

tion of the steel. The ingot should be heated so as to be thoroughly plastic throughout the mass. If the center of the piece is cooler than the outer portions, forging may result in internal tears or bursts. The finishing temperature of forging is an im-

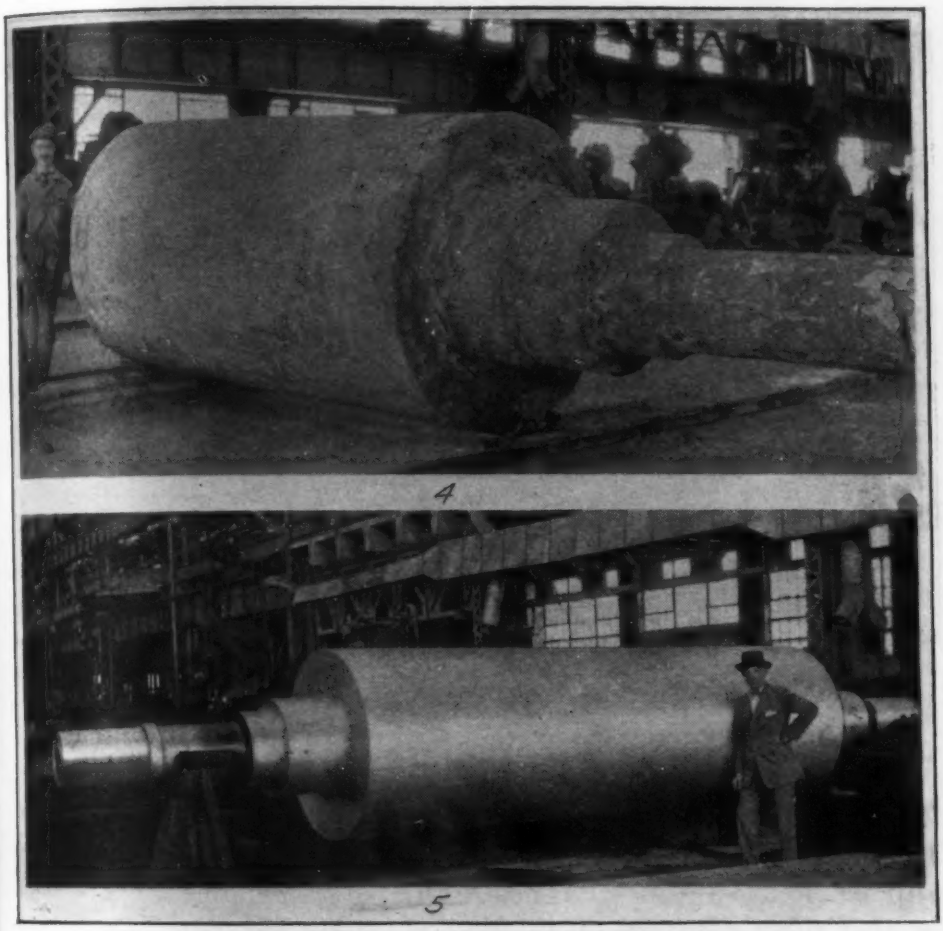


Fig. 4—Turbo-Rotor Field Forging. Fig. 5—Machined Turbo-Rotor Field Forging.

portant factor. Finishing at a low temperature, by a series of squeezes evenly distributed over the surface, breaks up the coarse grain growth which would otherwise be found in the finished forging.

The sequence of forging operations can best be explained by several examples. Fig. 4 shows a typical forging for a large rotor field shaft. The first operation in the pressing of this piece, is the rounding up of the ingot. It is the aim of this first working to consolidate the center of the ingot. For this purpose, the forging

tool must be heavy enough to permit the use of a wide die. Incidentally, this operation accomplishes the pressing in of the corners of the octagonal ingot, breaking up the columnar crystal structure which occurs at these edges, and the removal of the taper of the ingot.

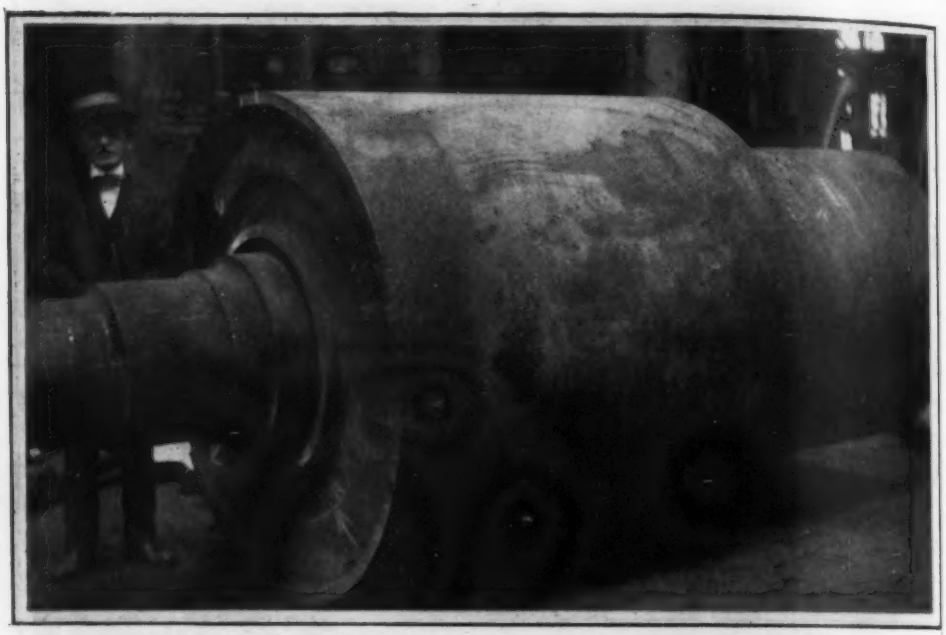


Fig. 6—Turbine Spindle.

The next operation in the forging of the piece illustrated (Fig. 4), is the setting down of one end to a smaller diameter. Two things should be remembered in accomplishing this. The first is, that the metal in contact with the face of the die does not slip or flow,—the metal beneath this surface flows. The second is, that the center line of an ingot is its weakest part. Too rapid reduction from large diameters to smaller ones may cause a transverse rupture beneath the point where the set-down is made. This is due to the different rate of flow of the metal at the outside and at the center of the forging.

To make a large set-down, such as the one at the front end of the forging illustrated, a V-tool is first used. This tool is in the form of a half wedge, one side being perpendicular to the top. It will be noticed in the illustration that the effect of this tool does not extend more than six inches from the outer edge of the body. The flow of metal caused by the use of this tool is concentrated

at its point. Further use would strain the metal beneath it too severely and rupture would result. The rest of the set-down is accomplished with a flat die. A large fillet is allowed. Work of

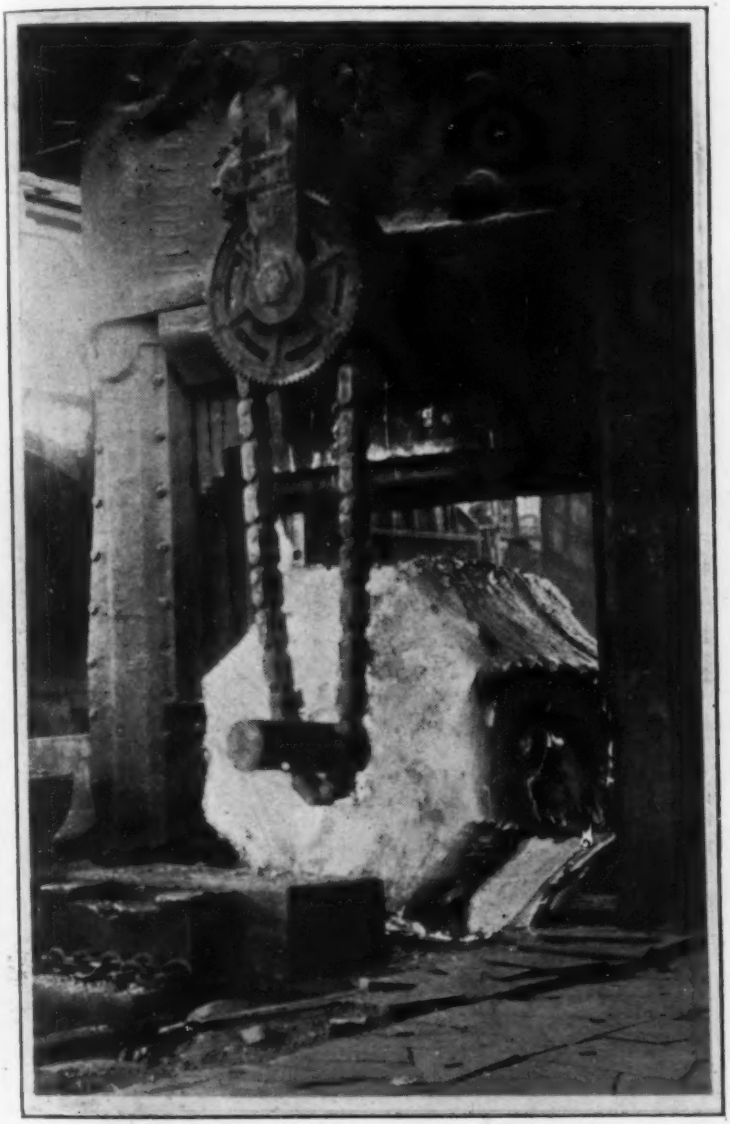


Fig. 7—Punched Billet Beneath Press on Roughing Mandrel.

this sort should be done slowly, and by small increments. Unbalanced strains along the center line of the ingot may result in cracks later in the process.

Several other points may be brought out in connection with this forging. No portion should be heated to forging temperature

without receiving some mechanical working. In the manufacture of forgings having large body diameters with sudden alterations of shape, care should be used to avoid the plane of weakness that results from heating only that portion of the forging which is to

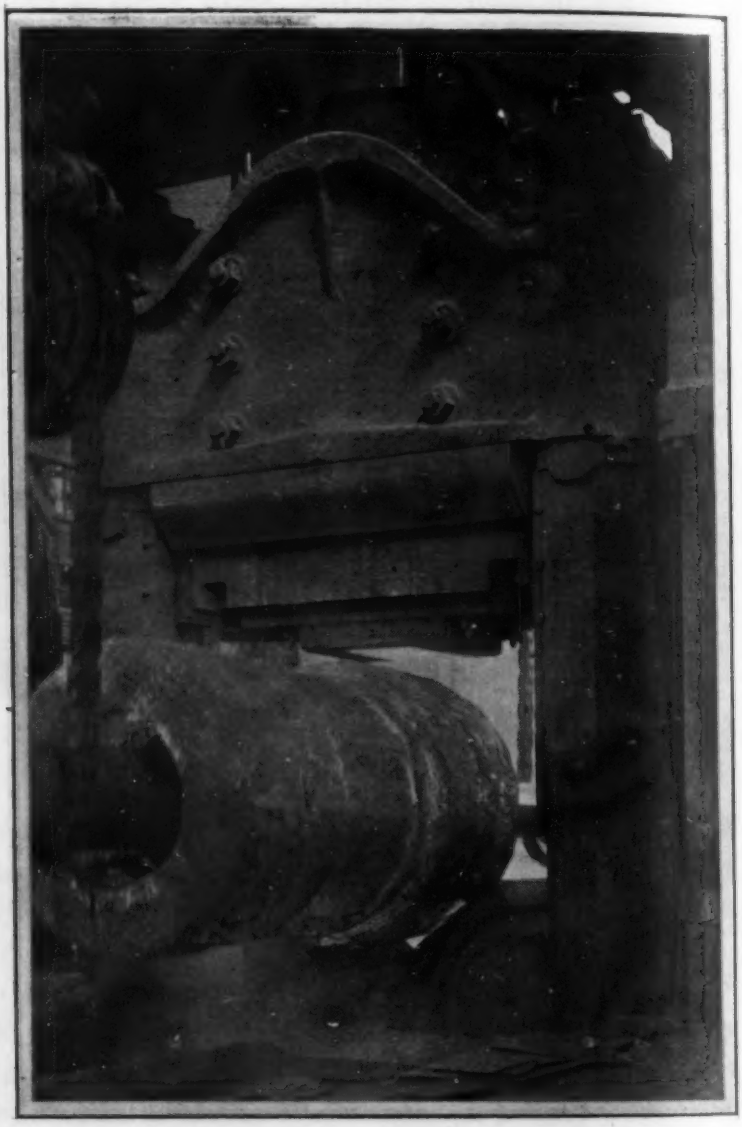
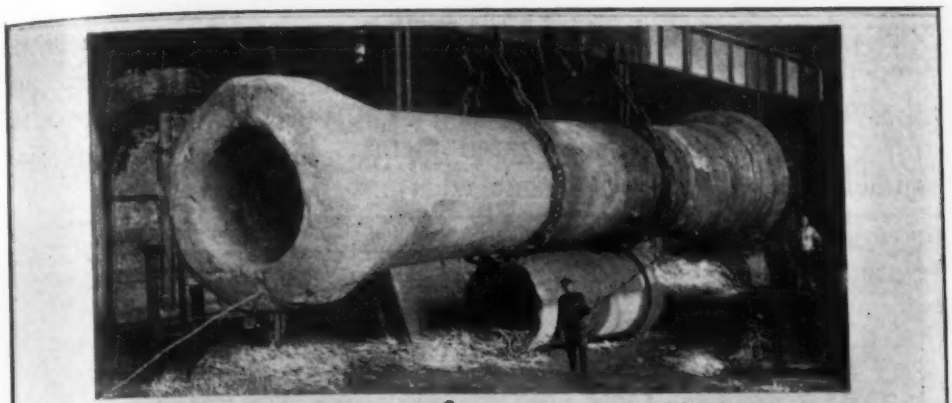


Fig. 8—Cylinder on Finishing Mandrel.

receive heavy work. One end of a long forging may be heated for further working, allowing a large portion to project through the furnace door. Before forging, it should be moved further into the furnace for a short period of time, to prevent the formation of any definite plane where the heating stops.



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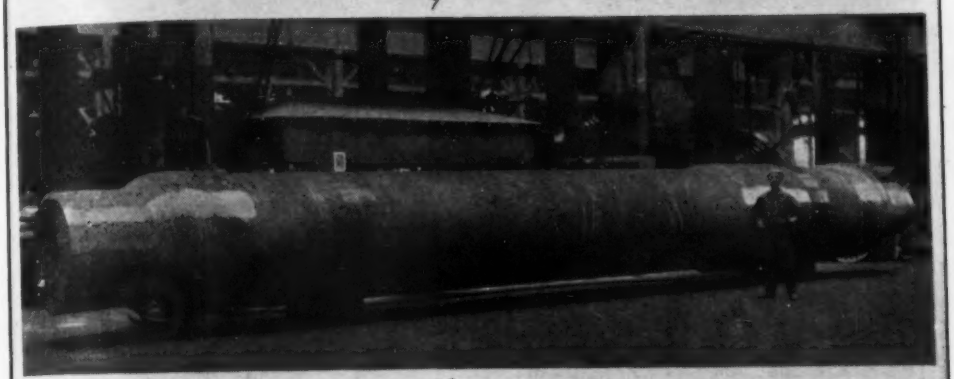

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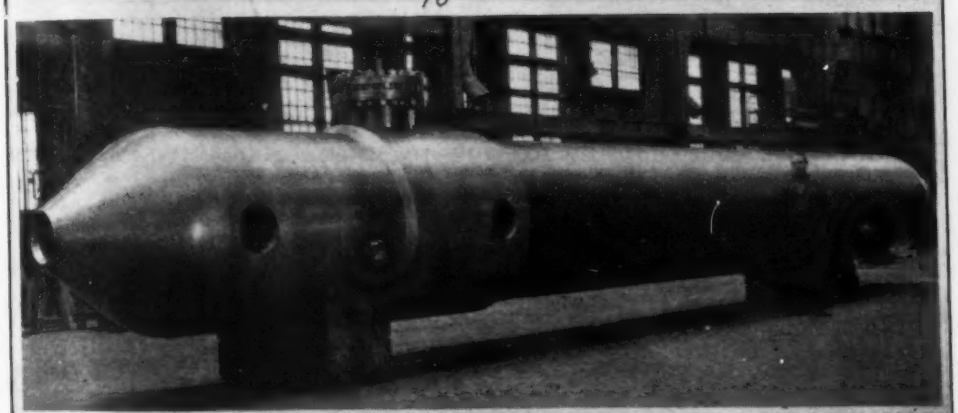

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Fig. 9—Forging for Gasoline Cracking Cylinder. Ingot Weight—270,000 Pounds. Fig. 10—Forging for a Gasoline Cracking Cylinder After Closing-In the Ends. Fig. 11—Finished Gasoline Cracking Cylinder.

A rotor field shaft forging after machining is shown in Fig. 5.

The top and bottom scrap may be cut either in the machine shop or under the press, at any time in the operation. The scrap is often an aid in handling the forging, and may be held in a chuck or porter bar. In that case it is cut from the forging after

the other working is completed. The amount of scrap to be cut depends on the open hearth practice with regard to the size and design of the sinkhead and ingot. The purpose is to remove the pipe and excessively segregated metal. If this is accomplished, sufficient scrap has been removed.

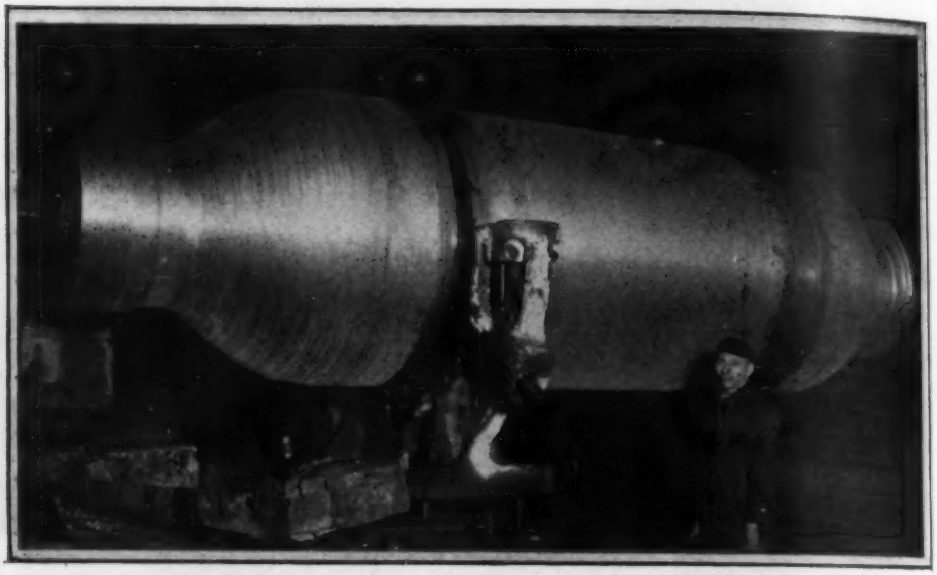


Fig. 12—Forging for a High Pressure Boiler Drum.

The turbine spindle forging illustrated in Fig. 6 brings up another consideration in forging practice. The physical properties of steel are improved along the direction of the mechanical working. Turbine spindles are subject to severe radial and tangential stresses. To provide working of the metal in the direction of these stresses, these spindles are best "upset." One or both ends of the spindle are first set down. The spindle is then turned vertically beneath the press, the set-down going through the hole in a bolster. The body of the spindle is then upset between the bolster and the cross-head of the press, or in some cases between top and bottom bolsters.

Many forgings of today are hollow, such as gun hoops, cylinders, turbine drums, and various large rings. In the manufacture of such pieces, the top and bottom scrap must first be cut from the ingot. This may be done either in the machine shop, or beneath the press. The longitudinal hole is made in the billet either in the machine shop, by hot coring, or by hot punching

under the press. In any case the comparatively weak central portion of the ingot is removed.

The billet with an axial hole, shown in Fig. 7, is then supported horizontally beneath the press, on a roughing mandrel.

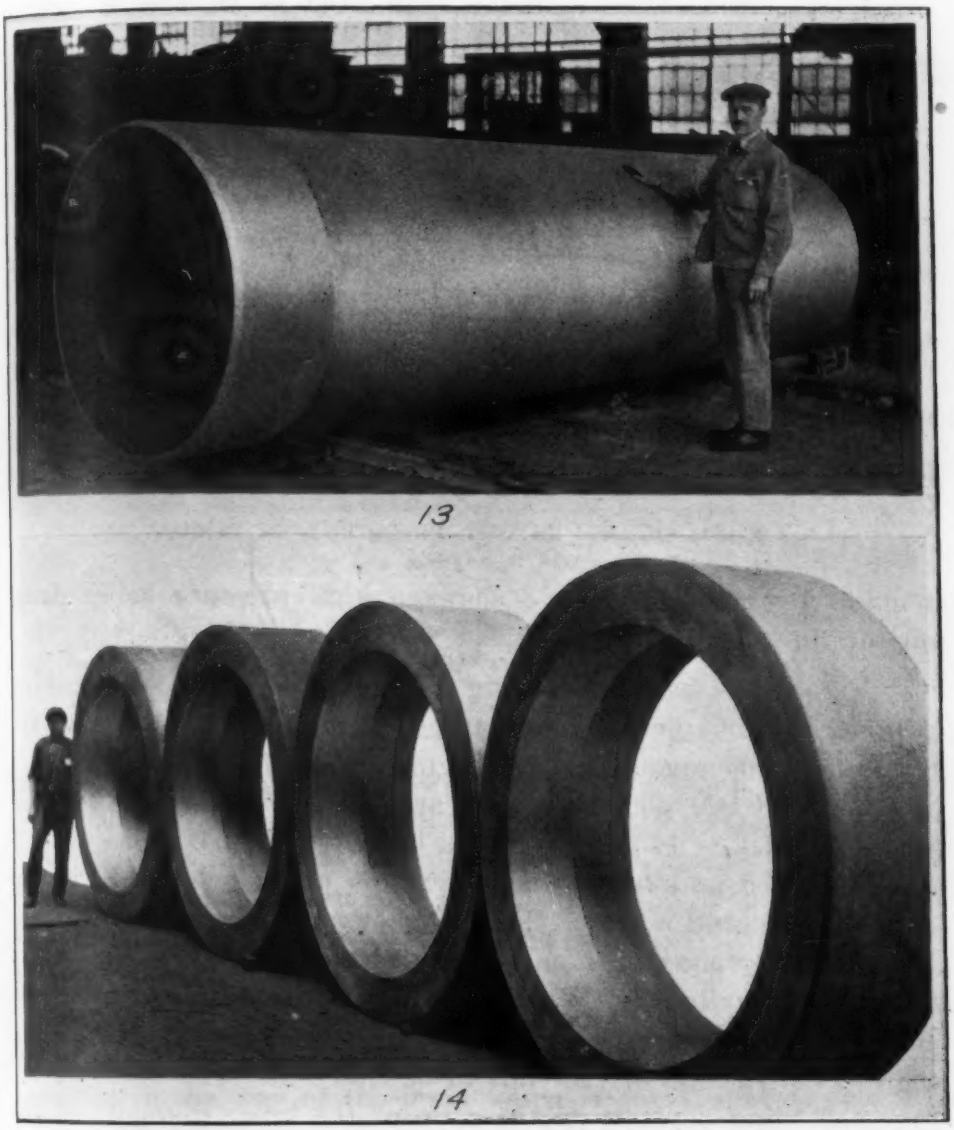


Fig. 13—Finishing Mandrel Forging. Fig. 14—Rock Crushing Roll Shells.

It is expanded, using a special die in order to work the metal circumferentially, and the diameter of the bore is increased. Larger mandrels are used as the cylinder is expanded. The forging may be supported by the mandrel which rests on vertical

supports. For the finishing operations, a V-die is used as a base, and the mandrel is not supported. Fig. 8 shows a cylinder on the finishing mandrel. The loose scale in the bore must be removed continually to prevent deep pitting. Care must be exercised on a thin-walled cylinder, supported as in Fig. 8, that it

Fig. 15—Machined Crankshaft Forging Ready for Twisting.

remains cylindrical. Fig. 3 shows a high pressure boiler drum on the finishing mandrel.

Fig. 9 shows a large forging to be used as a gasoline cracking cylinder. This picture shows the forging before the ends are closed-in. The ingot for this forging was an 82-inch "octagon," weighing 270,000 pounds. Low carbon steel was used. The finished cylinder is 44 feet, 8 inches long overall, 54 inches in outside diameter and has a wall thickness of 3 inches. It is machined inside and outside. Fig. 10 shows the forging after it has been partially machined and the ends closed-in. Fig. 11 shows the finished cylinder. When the ends of a cylinder are to be closed-in, the forging may be machined throughout the bore or on the inner diameters of the ends to be closed-in. The necessity for this machining depends on the ratio of the inner diameter of the cylinder to the bore of the closed-in portion. If this ratio is high, it may be necessary to machine the partially closed-in bore several times between operations to remove ruptures caused by the excessive reduction of the diameter.

Various types of hollow forgings are shown in Figs. 12 to 14. Fig. 12 is a high pressure boiler drum forging, made from a

63-inch "octagon" ingot. When machined it is 16 feet long, having an outer diameter of 56⅜ inches, and a wall thickness of $4\frac{3}{16}$ inches. It is made of 0.23 per cent carbon steel.

Fig. 13 is a photograph of a hollow forging mandrel, and

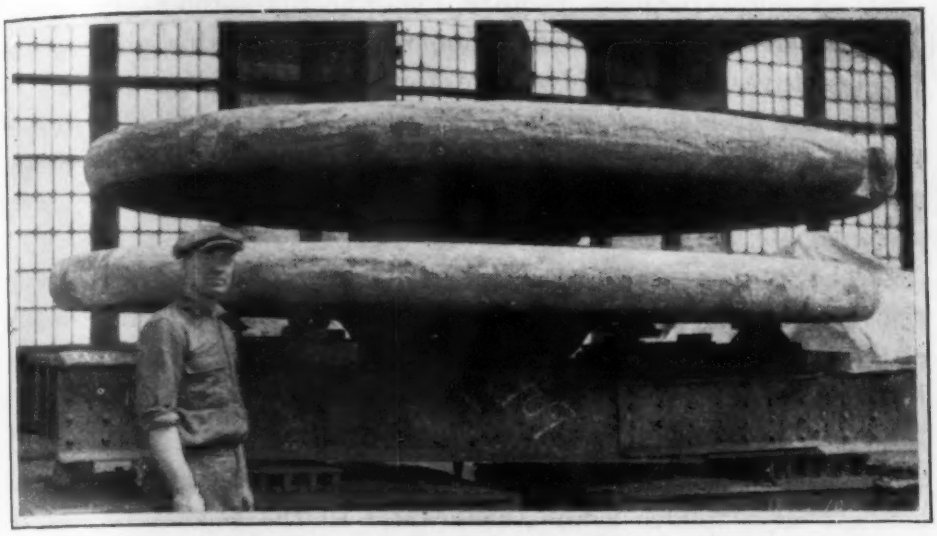


Fig. 16—Turbine Disc Forgings.

Fig. 14 a photograph of large rock crushing-roll shells. These may be forged in multiple lengths and cut apart in the machine shop.

Very often a large forging must be reheated as often as twenty times, due to the great amount of forging work to be performed on it. In each reheating there is a loss of metal due to scaling and this must be taken into consideration in choosing the weight of the ingot used. If any surface defects appear during the forging operations, the forging must be cooled in an annealing furnace, and the defects chipped out.

Crankshafts, such as the ones shown in Fig. 15, are first forged as slabs. The slab is then annealed, and then rough-machined in the way of the main journals, leaving fillets of large radius. The shaft is then heated and the cranks are twisted to the proper angles. The shaft must then be reannealed.

Large disc forgings which are subjected to tangential and radial stresses, are best forged with the axis of the disc coincident with that of the ingot. The block from the rounded up ingot is upset into the disc. The hub is formed by special dies. The cen-

ter is punched out, and the center portion of the ingot removed. Two turbine disc forgings are shown in Fig. 16.

Heat Treatment

All large forgings require some heat treatment to remove internal strains and to insure homogeneity. In this phase of the manufacture of extremely large forgings, each type presents its individual problems, and calls for special treatment. The proper heat treatment for a forging depends upon its size, shape, composition, the physical properties required, and its use. These factors are intimately connected.

The successful heat treatment of large forgings starts with the handicap of the initial condition of the metal. Large masses of steel cannot be worked to as low temperatures as smaller masses. Because of this, the grain structure of the forging as it leaves the press is naturally coarse, and non-uniform.

The principal aim of the heat treatment is to bring about homogeneity, and to refine the grain. In the accomplishment of this object, another obstacle is found. One of the principal factors in the effectiveness of any treatment is the rate of cooling through the critical range. With small objects this can be easily controlled. Because of the great mass of metal in large forgings, it is difficult to increase this rate of cooling, in fact it is impossible to cool the piece rapidly enough to prevent the formation of a coarse structure at the center of mass in a single treatment.

The treatment of large forgings usually begins with a heat several hundred degrees above the critical range, to bring about complete solution of the constituents and to eradicate the forging structure. The forgings may be cooled in the furnace or in the air, but if the cooling is accomplished outside of the furnace, the piece should be well protected from drafts of air, moisture, or any other condition which would induce non-uniformity. To refine the grain structure, a "stepped" anneal is resorted to. The initial heat is at a high temperature for the reasons given above. The second may be at a temperature slightly above the critical range, and this heat should be followed by one below the critical range. In some instances one or more additional heats above the critical range may be required to produce thorough grain refinement through the section.

The same or greater precautions must be exercised in the heating of these large masses of metal for treatment, as were explained in the heating of ingots for forging. It is of such importance that the mass of the metal be of uniform temperature, that in many cases the treatment may require as much as two weeks for completion.

In the cooling of large forgings by any method, the surface cools at a more rapid rate than the interior. This tends to produce a comparatively fine grain structure at the surface, which becomes gradually coarser towards the center of the mass. The effect of repeated treatments, as shown by experience, is to increase the depth of the zone of finer grain structure, and to cause a proportional improvement towards the center of mass. What cannot be accomplished with one heat on large forgings is often accomplished by several.

This principle should be borne in mind in treating comparatively large forgings requiring quenching to produce the physical properties desired. The metal should be conditioned for the quenching treatment by an air quench and draw. This accomplishes a certain amount of grain refinement, and makes the quench more effective. A second quench is frequently resorted to for the same reason.

It is sometimes difficult to prevent warpage or distortion in large and uneven masses of metal. Heating and cooling should be as uniform as possible. The forging should be well supported in the furnace to prevent this trouble. For this reason gun forgings and long shafts are suspended vertically. On quenching, the entire piece should be dipped as rapidly as possible.

Many large forgings, both of carbon and alloy steels, are successfully given treatments, including one or more quenching operations. Turbine discs of carbon, nickel and chromium-nickel alloy steels show superior physical properties by this method of treatment. Large, high carbon alloy steel rolls are hardened to over 110 scleroscope hardness. Before giving large masses of metal a quench, it is best first to bore the forging to relieve the weak center line of the ingot, and thus increase the effectiveness of the quench.

Testing

The utmost care is necessary in the testing of large forgings

to be sure that the condition of the metal at all parts subject to strain is indicated. The locations of the test bars should be chosen to represent working conditions as nearly as possible. In a large forging, no single test bar can represent the average condition of the metal. The center line of the ingot is the weakest part of the forging. The smaller sections of the forging will show better properties than the larger portions, because they have received more mechanical work, and are also more affected by the heat treatment. For the same reason, test bars taken at the surface of a forging will show better properties than those taken further into the mass. Enough test bars should be taken to represent the various sections subject to strain in use.

Photomicrographs, etch tests, and sulphur prints are all useful in showing the grain refinement, effect of working, the presence of non-metallic inclusions, and the segregation of any elements.

To be sure of the solidity of the piece, and the absence of shrinkage cavities, or other openings, there is nothing quite as satisfactory as the boring of the piece and the inspection of the bore. All large rotor field shafts, turbine spindle shafts, and similar objects should be bored, and the bore inspected for cracks and other injurious defects that may have been produced by forging and heat treatment. The bore should be smooth and carefully examined with a bore searcher. These are of various forms,—either a simple light and mirror, or a series of reflecting mirrors with a telescope for magnification. Periscopes are made in the form of sectional tubes, carrying their own lights, and magnifying the surface about two and one-half diameters. Any small imperfection may be removed by enlarging the bore. If the bore is clean, we may be reasonably sure of the rest of the forging.

Various methods of testing the rest of the mass are in existence. The changes in resistance to the passage of magnetic flux, due to segregation or the presence of non-metallic inclusions, might be recorded on large forgings, and adapted to their testing as it is now used on smaller masses.

X-ray apparatus will no doubt be successfully applied to the testing of larger masses of metal, and should provide a useful method of investigation.

An English company manufactures a so-called "clink detector." This is attached to the forging during cooling, and is some-

what similar in action to the seismograph, although not at all similar to it in construction and design. It records any shock received by the piece, which might be caused by a clink or the internal cracking of the piece, due to the giving way of the metal to some unbalanced strain.

Small non-metallic inclusions are always found in steel to a certain extent. If they are too large and frequent, they may make it impossible to obtain the desired physical properties in the forging. Large slag inclusions, visible to the naked eye, are a purely local condition and do not necessarily indicate poor condition of the metal if they do not occur in large clusters. Unless they occur on a journal or similar place, they are not a serious defect of the forging.

The development of the manufacture of large forgings is still progressing. With turbine units rapidly approaching the 100,000 kilowatt mark, with boilers developing around 3,000 pounds per square inch pressure, and the growth of the cracking of oil at high temperatures and pressures, the demand for large forgings formerly furnished by instruments of war is gradually changing to a peacetime basis.

THE METALLURGICAL ENGINEERING OF AIR CRAFT PROPELLER HUBS

By W. J. Merten

Abstract

This paper describes the development from a metallurgical standpoint of an airplane propeller hub. Such a development requires not only the consideration of the material used but also the design of the component. In cases discussed in this paper, it has been found necessary to redesign the hub which had previously been used in airplane work.

The author has described in detail the procedure in this development.

Photomicrographs of the structures obtained in actual practice are included with the paper.

FROM a casual survey of the development of air craft propellers as shown in Figs. 1 and 2, one rarely appreciates the difficulties that had to be overcome and the profound study, and detailed and laborious researches involved in the successful production of such a unit. The accomplishment of a satisfactory performing propeller seems only natural and logical and it is hard to visualize that anything less complete or perfect has ever existed.

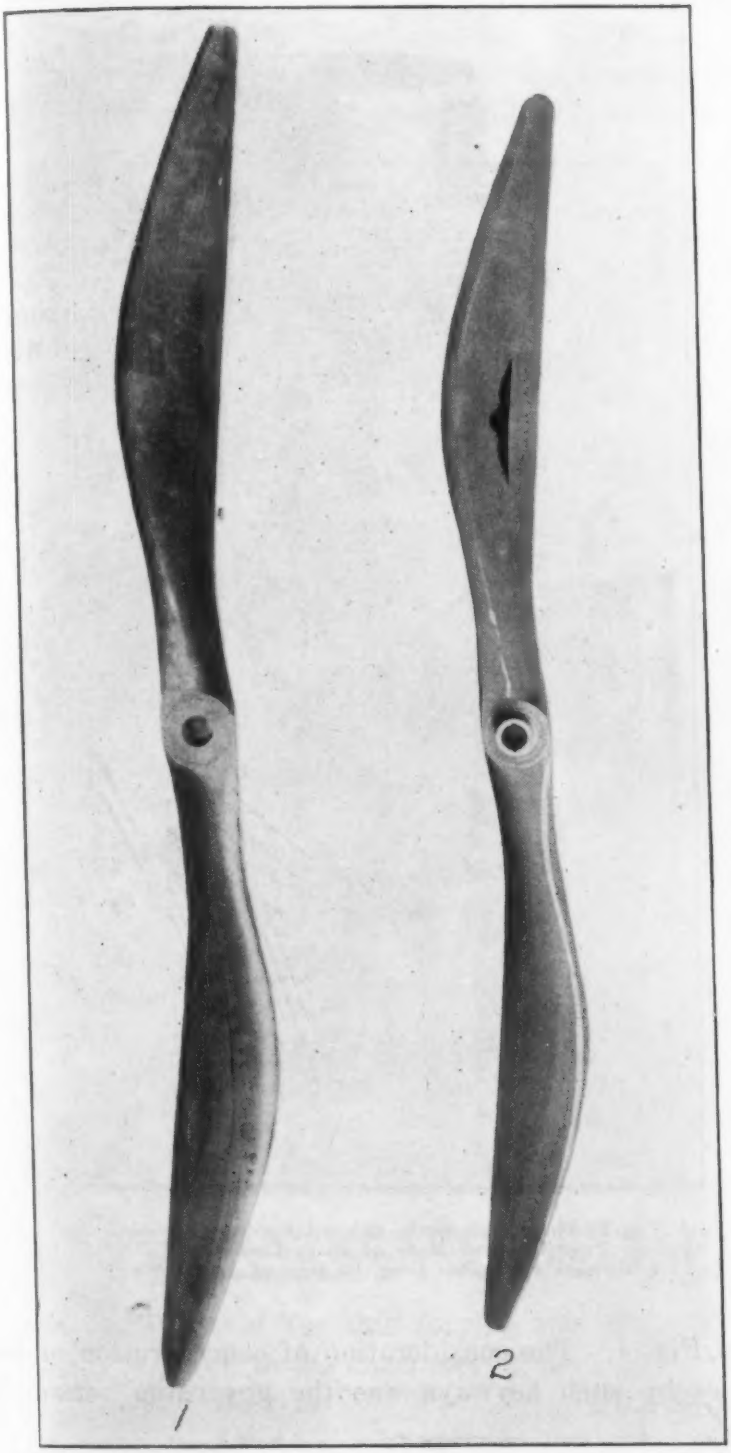
It is still more difficult to picture the importance of an exact and carefully planned metallurgical practice in the manufacture of the hub in order to assure proper performance of the propeller. Considering, however, that the twelve-cylinder engine transmits through the hub approximately 420 horsepower at a speed of 1750 revolutions per minute, the conception of the magnitude and importance of the apparently unimportant part is readily obtained.

This investigation is of particular interest since it gives a comparison of characteristics and properties of chromium-vanadium steels heat treated in the rolled and forged condition.

Material and Design

The original design of the hub (Fig. 3) specified an ordinary plain carbon steel and consisted of a cylinder into the bore of which were milled four keyways 4¼ inches long, arranged 90 degrees apart. This design was changed to the double splined hub as

The author, W. J. Merten, member A. S. S. T., is metallurgical engineer with the Westinghouse Electric and Manufacturing Company, Pittsburgh.



Figs. 1 and 2—Photographs Showing Airplane Propellers. This Paper Deals with the Metallurgical Study of the Production of a Satisfactory Hub for these Propellers.

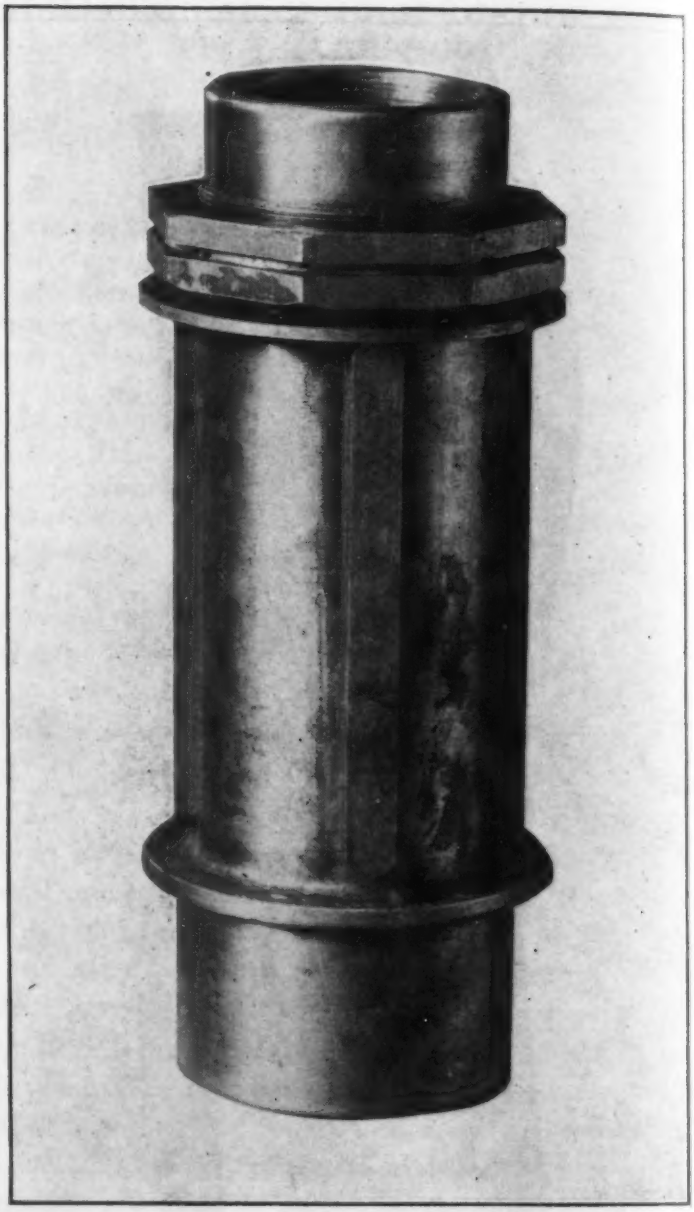


Fig. 3—Photograph of the Original Design of the Hub Used in Airplane Propellers and Made of Plain Carbon Steel. This Hub had 4 Keyways 4¼ Inches Long, 90 Degrees Apart.

shown in Fig. 4. The consideration of concentration or localizing of stresses by such keyways was the governing reason for this change.

A thorough study of the magnitude and character of the stresses that were encountered compelled the selection of an alloy steel

in order to assure an ample factor of safety to permit satisfactory performance.

A chromium-vanadium steel of the following composition was chosen and obtained in 4¼-inch diameter rolled bars. A check

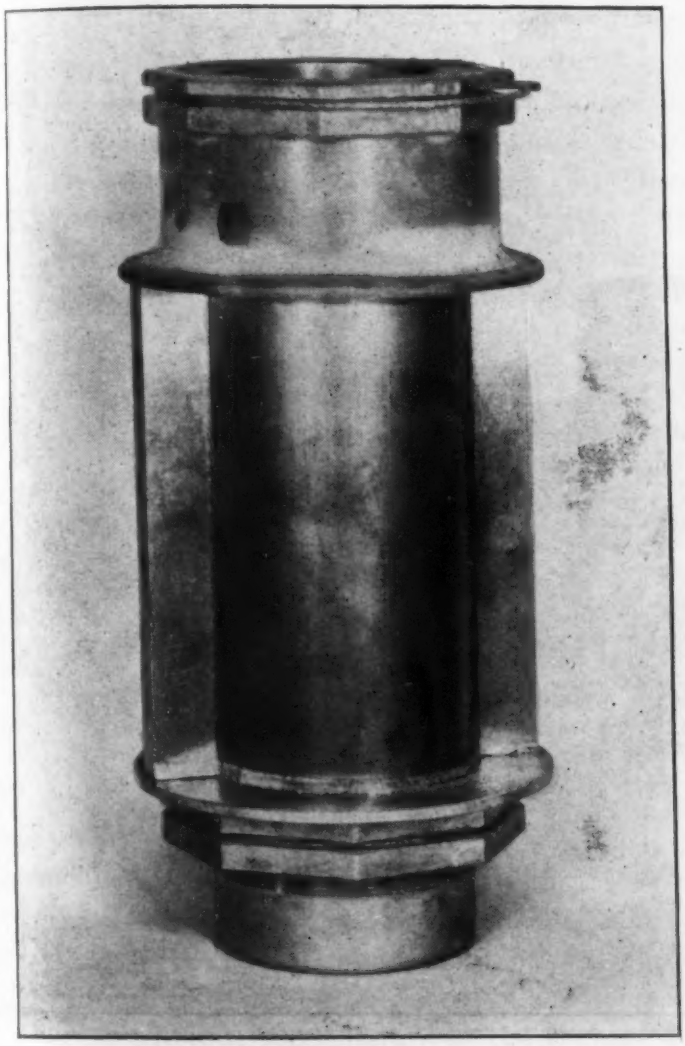


Fig. 4—Photograph of an Airplane Propeller Hub Which was Designed to Replace the Hub Shown in Fig. 3. This Hub was Made of Chromium-Vanadium Steel.

analysis of every bar used for this forging was made to insure proper material in regard to the chemistry of the steel.

	Per Cent		Per Cent
Carbon	0.45–0.55	Phosphorus	0.04
Manganese	0.50–0.80	Sulphur	0.04
Chromium	0.80–1.10	Silicon	0.15
Vanadium	0.15–0.18		

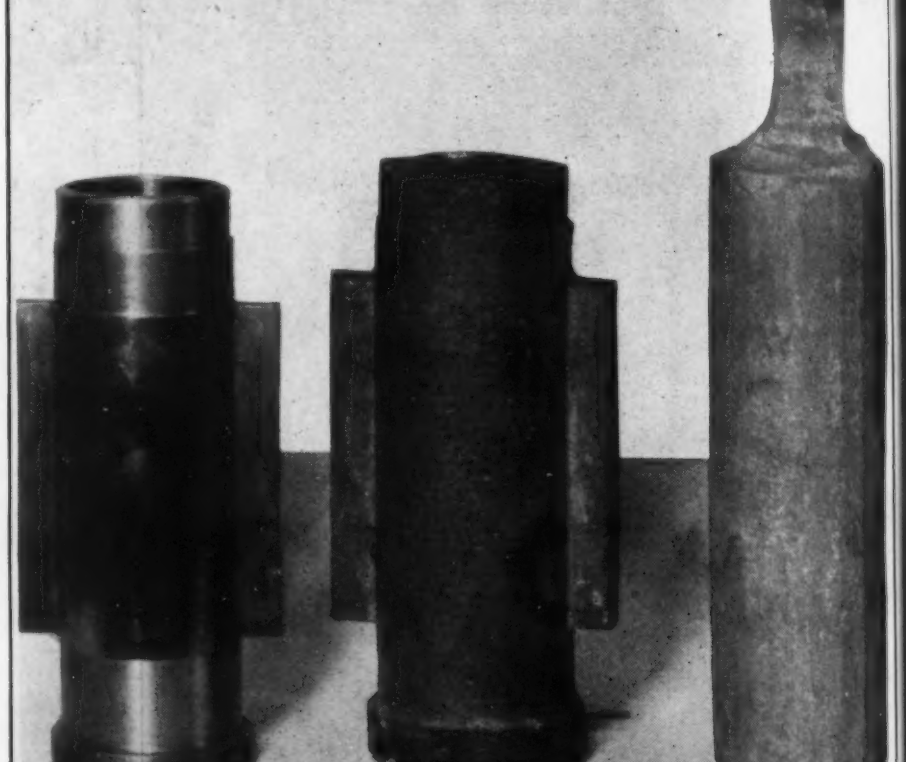


Fig. 5—Photographs Showing the New Type of Hub in 3 Stages of Completion. The Forging with the Tong Hold is Produced in 2 Steps, the First Being the Reduction of the Rolled 4¼-Inch Bar into the 3¾-Inch Forging Blank. The Center Figure is the Second Step in the Forging Operation Wherein the Splined Blank is Produced by Forging in Retaining Dies. The Figure on the Left is that of the Finished Hub.

The forging was produced in two steps, the first being a reduction of the rolled 4¼-inch slug into a 3¾-inch forging blank with tong-hold (Fig. 5). This forging operation was conducted at approximately 1900 to 2000 degrees Fahr. (1040-1090 degrees Cent.) This ½-inch reduction is practically the only real ho

working the hub receives, and certainly produces favorable conditions as will be seen from physical test results tabulated.

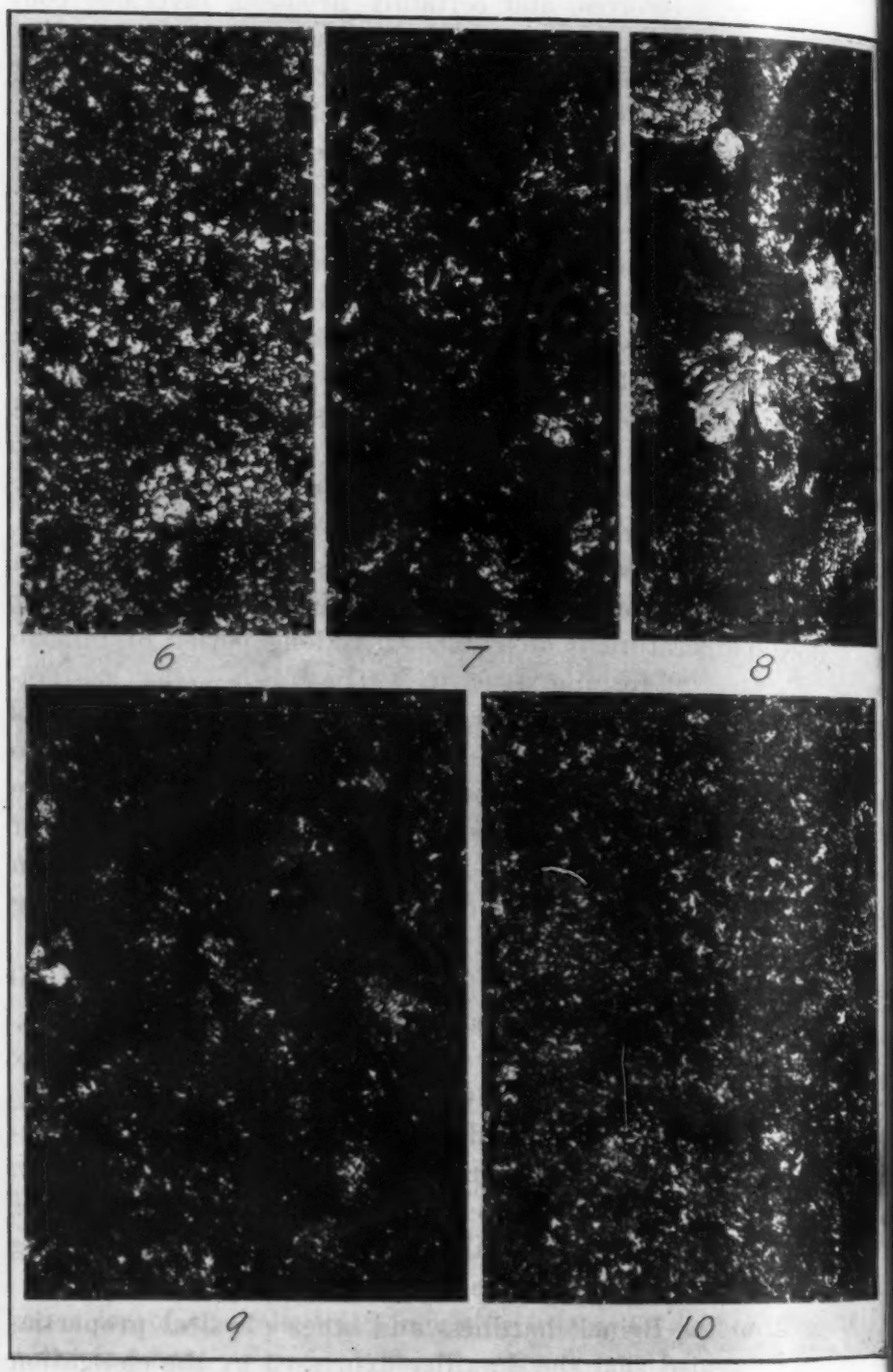
The second step is the drop forging of the splined blank in retaining dies. This work is done at a yellow heat of approximately 2200 degrees Fahr. (1200 degrees Cent.) and the steel receives very little actual hot work or kneading during this operation. The high heat consequently leaves the material in a coarsely granular condition. A photomicrographical illustration of this change in crystal structure is presented in Figs. 6, 7 and 8. Fig. 6 represents the mill-annealed bar stock. Fig. 7 is a section of the forged blank and Fig. 8 a section of the drop forging in the coarsely granular, unannealed condition. To remove this unsatisfactory structural condition and improve the machinability of the forging it was annealed at 1625 to 1650 degrees Fahr. (890-900 degrees Cent.) soaking at this temperature for a minimum time of 1½ hours and cooling in the furnace, giving a Brinell hardness of 200 to 210 and a fairly good machinable steel. It is quite essential that the soaking at the high temperature is of a sufficiently long period of time to remove all traces of forging structure. The forging was then hollow-drilled and a fracture test for grain structure examination was made. On this test specimen a Brinell hardness test was also made to verify the results of the previous tests. Examination of the bore for slag pockets and oxide inclusions concluded the inspection of the hub prior to heat treatment. If the piece passed this inspection satisfactorily the hub was put through the following heat treating process.

Heating for Hardening—Heat slowly and uniformly to 1650 degrees Fahr. (900 degrees Cent.) and hold for 1 hour.

Quenching—Quench in water and cool to approximately 212 degrees Fahr. (100 degrees Cent.)

Tempering—Reheat immediately in the furnace to 1100 degrees Fahr. (600 degrees Cent.) and hold for 1 hour. Cool in the furnace to approximately 575 degrees Fahr. (300 degrees Cent.), then cool by quenching in boiling water. Hold in boiling water ½ hour.

A check on the Brinell hardness and other physical properties of the steel revealed that the ductility expressed by the elongation and the reduction of area, and the machinability expressed by the Brinell hardness were unsatisfactory. This lack of machinability was soon confirmed by the machine shops. Table II gives



Figs. 6, 7, 8, 9 and 10—Photomicrographs of the Various Structures of the Chromium-Vanadium Steel Used in the Production of Airplane Propeller Hubs. Fig. 6 Represents the Mill-Annealed Bar Stock. Fig. 7 is a Section of the Forged Blank and Fig. 8 is a Section of the Drop Forging in the Coarsely Granular Unannealed Condition. Fig. 9 is a Photomicrograph of an Annealed Drop Forging. It will be Noted that this is a Finer Grained Structure than the Annealed Rolled Bar Stock. Fig. 10 is a Photomicrograph of the Structure of the Finished Hub. Magnification 100x.

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Table I

El. Limit Lbs. Sq. In.	Yield Point Lbs. Sq. In.	Ult. Tensile Lbs. Sq. In.	% Elong.	% Red. Area	Brinell
Temp.					Rolled, Forged

Table I

Temp. Tempering	El. Limit Lbs. Sq. In. Rolled	El. Limit Lbs. Sq. In. Forged	Yield Point Lbs. Sq. In. Rolled	Yield Point Lbs. Sq. In. Forged	Ult. Tensile Lbs. Sq. In. Rolled	Ult. Tensile Lbs. Sq. In. Forged	% Elong. Rolled	% Elong. Forged	% Red. Area Rolled	% Red. Area Forged	Brinell Rolled	Brinell Forged
1110°F. ..... 600°C.	103,000	108,000	106,400	119,000	133,100	144,850	17.1	16.1	49.9	50.6	269	293
1250°F. ..... 675°C.	90,500	89,000	94,250	96,500	115,000	123,400	22.7	20.8	59.6	60.1	225	254

Table II

	Elastic Limit Lbs.Sq. In.	Yield Point Lbs. Sq. In.	Ult. Tensile Lbs. Sq. In.	Elong. %	Red. Area %	Izod	Brinell
Bar as rolled	43,500	47,850	90,875	29.1	60.3	29	
						19	206
	41,500	49,000	90,250	29.3	61.8	15	
Blank After Forging...	73,200	89,250	152,000	12.7	28.1	2	
						2	210
	77,500	.....	148,000	12.9	35.	2	
Drop Forging not Annealed	66,000	.....	129,500	Broke at Shoulder		2	
						1.5	220
	62,500	99,250	122,500			2	
Drop Forging Annealed.	40,500	45,925	107,675	18.1	36.3	7	
						6.5	210
	36,700	44,750	104,000	19.8	36.7	5	
Heat Treated*	78,500	80,700	109,825	25.2	65.2		228
	78,500	80,300	102,800	24.2	65.2		

*These results are lower than those given in Table I because of carbon, chromium and nickel percentages being all on the low side of the specification.

the values referred to. The heat treatment outlined above had given satisfactory results over quite a period of time on rolled bars of this steel and it was quite unexpected to find a Brinell hardness of 293 after a 1100-degree Fahr. (600 degree Cent.) tempering operation instead of around 255 as formerly on heat treated rolled stock. This Brinell hardness of 255 is considered the limit of good machinable hardness for an alloy steel. Additional tests confirmed the conclusion that a 1100-degree Fahr. (600 degree Cent.) tempering heat is not sufficiently high to produce machinability consistent with high ductility and resistance to dynamic stresses. It was therefore necessary to raise the tempering heat to 1250 degrees Fahr. (675 degrees Cent.) to obtain the proper Brinell hardness and machinabilty. Ordinarily this tempering heat is considered excessive and runs too dangerously close to the lower critical point for general application.

Table I of comparative tensile test results and Brinell hardness of rolled versus forged chromium-vanadium steel of the above referred to composition shows a decided difference in the magnitude of these values and proves that a forging operation is of very great benefit in toughening the steel and producing greater strength. It requires, however, higher temperatures for tempering.

The photomicrographical analysis reveals that the annealed drop forging (Fig. 9) has a finer grain structure than the annealed rolled bar stock (Fig. 6.) This same difference in grain size is probably the factor influencing the hardness and allied physical properties of the forging in the heat treated condition and compelling the higher tempering temperature for sufficient ductility and to produce such physical characteristics and properties as are essential for the satisfactory performance of appliances of this type. Fig. 10 is a photomicrographical representation of the structure of the finished hub. Very consistent and gratifying results were obtained all through the period of manufacture of these hubs—of which approximately one thousand have been in actual service for quite a period of time (over one year). As a result of this investigation a permanent difference in tempering temperatures for rolled and forged chromium-vanadium steels has been incorporated in the process specification for the heat treatment of these steels and is adhered to very closely and has insured consistent values obtained from physical tests from which prediction for proper performance can be made.

HEAT TREATMENT OF HIGH SPEED STEEL DIES

By C. B. Swander

Abstract

This paper describes in detail a method for hardening high speed steel dies and circular form tools, without scaling, blistering or distorting to any marked degree.

The author uses tightly sealed graphite crucibles, with a small amount of silica sand and charcoal in the bottom, and the normal hardening temperatures for high speed steel. A number of precautions are outlined.

Dimensional changes to be expected of tools made from round and rectangular stock are discussed.

WITH the increasing use of high speed steel for dies, the steel treater has been compelled to improve his hardening practice. Only dies of the simplest form can be ground on all sides after hardening. Fully 95 per cent are made to finished dimensions before hardening. This means that the hardener must heat treat such work without scaling, blistering or distorting to any marked degree. The average steel treater finds this difficult to do if he uses the ordinary method of heat treatment. This article is written for his consideration and discussion.

Many processes have been proposed and many used, but in the average shop it is usually thought that it is impossible to heat treat such work in a satisfactory manner without making many elaborate additions to their equipment.

The writer has tried many processes and combinations to meet all of the above requirements, but with the endeavor to make the process practical and economical and at the same time produce the proper grain refinement and secondary hardness with the necessary toughness.

Most of the pack hardening processes proposed are treacherous and only produce a surface hardness, with no secondary hardness, due to the carburizing action and the low heat used. Those methods using high enough heats to bring out the secondary hardness are still more treacherous, slow, and rather expensive to

A paper presented before the Spring Sectional Meeting of the Society, Moline, Illinois, May 22, 1924. The author, C. B. Swander, is metallurgist, Wagner Electric Corporation, St. Louis.

operate. The salt baths seem promising where large quantities are to be hardened, but are expensive to operate where only a few dies at a time are to be hardened.

The final process as adopted and used by the writer for over a year requires the following equipment:

Equipment

1. A preheating furnace with a minimum door opening as follows: height 12 inches and width 15 inches, preferably larger.
2. High heat furnace with same minimum door opening as preheating furnace. Preferably with a heating chamber 15 inches high x 18 inches wide and 24 inches deep, of semi-muffle type, gas fired.
3. Oil quenching tank.
4. Oil tempering bath.
5. Cyanide or lead hardening furnace with a steel pot at least 8 inches in diameter and 10 inches deep, to use for a salt tempering bath.
6. Three graphite crucibles and lids size No. 10 or 12, depending on size of work to be hardened.
7. Pyrometers and thermometers. Preferably a rare metal thermocouple for the high-heat furnace.
8. Necessary tongs and fixtures for the work at hand.

All of the above equipment is usually found in the average hardening room, with, perhaps, the exception of a high-heat furnace of the above dimensions, graphite crucibles and salt for the tempering bath. An ordinary heat treating furnace can often be converted into a high heat furnace by changing to a larger sized burner, particularly the one burner type.

The Process

The process is carried out as follows:

Inspect the crucibles and lids to see that the lids fit tightly. Put about ¾ inches of a mixture of ⅓ charcoal and ⅔ silica sand in the bottom of each crucible. On this place a disk of

graphite made from a crucible lid. Preheat two of the graphite crucibles and lids in the preheating furnace to 1500-1600 degrees Fahr. (815-875 degrees Cent.), and one of the crucibles with tight fitting lid in the high-heat furnace to 2300 degrees Fahr. (1260 degrees Cent.). One of the preheated crucibles is then removed from the preheating furnace. The work to be hardened is inserted. The crucible and contents are returned to the preheating furnace. As soon as the work is preheated to 1500-1600 degrees Fahr. (815-875 degrees Cent.), this crucible is removed and the one in the high-heat furnace removed and the work quickly transferred to the high-heat crucible, the lid is carefully placed into position and the crucible and the work which is just received placed in the high-heat furnace held at 2250-2300 degrees Fahr. (1230-1260 degrees Cent.), depending upon composition of steel, for a pre-determined length of time, which naturally varies with the dimensions and weight of the work being hardened. The time varies from 5 to 15 minutes, 10 minutes being satisfactory for all but light pieces and pieces 1 inch through or over. The crucible and contents are then removed from the high-heat furnace, the lid is then removed and the work quickly quenched into a good grade of quenching oil. When cooled to about 150-200 degrees Fahr. it is transferred to a hot oil bath maintained at about 400 degrees Fahr. and tempered for 10-15 minutes, then finished tempered in a salt bath for about 20 minutes at 1100 degrees Fahr. (595 degrees Cent.). Then it is cooled in oil. The salt film is then dissolved off in hot water and the die allowed to cool in air.

By using two crucibles for preheating, the cycle becomes continuous, as it always has preheated work ready for the high-heat crucible when the latter is empty. If the work is of small section, one preheating crucible is often sufficient.

The dies come out remarkably clean, free from all blistering and scaling, all sharp cutting edges in perfect condition and with small dimensional changes. Such dies have a hardness of Rockwell C-60-63, scleroscope 85-95, Brinell of 600-652 and absolutely file hard, with good grain structure.

The scleroscope hardness usually varies between 90-95, which is at least 5 points higher than is normally obtained by the quick open fire method, used on tools that can be ground.

The temper at 1100 degrees Fahr. as compared to no temper

increases the scleroscope hardness from 2 to 5 points and at the same time reduces the Rockwell hardness from 2 to 3 points on the C-scale, with practically no change in Brinell hardness. It also increases the toughness to a marked degree, which is easily demonstrated by breaking a thin section say ¼ x ½ inch. French and Strauss show this very clearly in their paper on "Effect of Heat Treatment on Lathe Tool Performance and Some Other Properties of High Speed Steels." (September, 1923, issue of TRANSACTIONS.) They show an increase in fibre stress and deflection after a 1100 degree Fahr. temper. The author believes that the high temper is necessary for die work when hardened by this method, due to the added toughness which it gives, which is so important in dies for punch-press work. Hardness values are fixed and no further heating up to 900 degrees Fahr. (485 degrees Cent.) (which is as high as the author has tried) for a short or long period will change them. The high temper also helps to prevent grinding cracks which often means failure of the die.

PRECAUTIONS

The precautions which should be taken into account in this method of heat treatment are as follows:

1. Have high-heat furnace equipped with a good pyrometer, preferably with platinum, platinum-rhodium thermocouple, and checked often.
2. Before using new graphite crucibles, anneal them carefully and heat to 1600 degrees Fahr. (870 degrees Cent.) with lids removed to burn out surface graphite to prevent it falling on the work to be hardened.
3. See that the lids fit tightly before starting work.
4. Always have crucibles side by side when making transfer, and do not have lids removed longer than necessary.
5. Transfer work quickly from the preheat crucible to the high-heat crucible, and likewise from the high-heat crucible to the quenching oil.
6. Do not allow the hardened pieces to lie around long before tempering. The sooner they are tempered, the less the danger of breakage.
7. After tempering in the salt bath, be sure to let the pieces get cool before placing them in the hot water to remove the salt.

Dimensional Changes

This method, since the finished surfaces are not scaled and pitted, as in open fire work, has given the author an excellent opportunity to study dimensional changes. Not on any certain size test bars, protected by steel clamps and caps as other investigators have done, but on production dies and tools of varying dimensions.

Pieces made from round rolled high speed steel in the annealed condition have always expanded slightly on the linear dimension, when treated by this method, and shrunk slightly on the cross-sectional dimension, regardless of the varying proportions of these dimensions. A piece 1½ inches in diameter by 3 inches long will usually shrink more on the ends than in the center. The center on such a piece usually shows no movement at all. If, however, the dimensions are reversed, that is, 3 inches in diameter by 1½ inches thick, the piece gets slightly smaller on the 3-inch dimension and larger on the 1½-inch dimension, with a slight bulging in the center. The average expansion in the linear dimension on some 50 pieces measured, was 0.0009 inch per inch of length, and the average shrinkage in the cross sectional dimension on the same pieces was 0.0007 inch per inch.

This linear expansion of 0.0009 inch per inch checks very closely with curves given by Grossmann in his paper, "The Change in Dimensions of High Speed Steel in Heat Treatment" (May, 1922, issue of Transactions). Mr. Grossmann, however, did not take into consideration the cross sectional changes.

My experience has shown that dies made from rectangular sections show much smaller dimensional changes than those made from round bars. They usually expand slightly in the center on the linear dimension, the edges showing little movement. On the width they usually expand slightly in the center and shrink slightly on the ends. On thickness they practically always expand, the expansion being more pronounced in the center; here again showing the bulging effect previously mentioned.

Some data along this line may be of interest to show the small change that rectangular stock undergoes in hardening by this method. A few 6-slot motor laminæ dies made from bar stock 1¼ x 4 inches were ground on all sides, measured carefully,

hardened and tempered and again measured, showed the following results:

Table I
Dimensional Changes of High Speed Rectangular Bar Stock

Size Before Treatment	Size After Treatment			
Inches	In Center	At Ends	Scleroscope Reading	Rockwell Reading
Length .....5.072 Width .....3.943 Thickness 1.1235	5.072 3.9435 1.1247	3.942	92	C-63
Length .....5.933 Width .....3.724 Thickness 1.063	5.933 3.725 1.0635	3.724	93	C-61
Length .....5.883 Width .....3.422 Thickness 1.0595	5.883 3.422 1.060	3.420	92	C-61
Length .....5.941 Width .....3.591 Thickness 1.070	5.938 3.591 1.071	3.588	90	C-61

Treatment:—Preheated 1600 degrees Fahr. (870 degrees Cent.) for 30 minutes. Transferred; in high-heat furnace for 13 minutes at 2300 degrees Fahr. (1260 degrees Cent.). Quenched in oil. In oil at 400 degrees Fahr. for 15 minutes. In salt at 1100 degrees Fahr. (595 degrees Cent.) for 25 minutes. Cooled in oil.

Discussion

You no doubt have observed that the main difference between the method outlined and standard practice is the use of graphite crucibles and lids, with about ¾ inch of a mixture of ⅓ charcoal and ⅔ silica sand by volume in the crucibles in which the work is heated. The reason for the use of graphite crucible is that the gases therein are reducing at all times, thus preventing the formation of scale. These gases do not carburize at the pre-heat temperature, and show only a slight carburizing effect at the high heat temperature, this carburization being well under the eutectoid range.

The graphite crucibles stand the high heats well, and are comparatively cheap.

It is important that the work be thoroughly protected from oxygen at all times. For this reason the added precaution is taken of using the small quantity of charcoal, particuarly in the preheat crucibles. If by chance scale is formed during the preheat operation, it is reduced by the carbon monoxide present at

the high heat, producing a soft skin or decarburized surface. This is the reason that emphasis is placed on tight fitting lids and transferring work quickly.

Large pieces, such as form tools, are handled individually, resting directly on the graphite slab, while small pieces are suspended by wires from an umbrella-like fixture made of sheet steel free from scale.

The process is quite flexible and need not be followed to the letter. For instance, if the operator feels that full secondary hardness is not required, he can use a lower heat, say 2200 degrees Fahr. (1205 degrees Cent.), and a low temper or quench into salt at 1100 to 1300 degrees Fahr. There are many who advocate and use the lower heats on delicate dies not requiring full secondary hardness.

The tendency of many manufacturers using high speed steel for dies has been to use a 14-per cent tungsten steel due to its lower hardening temperature, thereby eliminating as much danger of scaling and pitting as possible. But by the above method, the danger of scaling and pitting is eliminated. Low tungsten steels are more sensitive to heat treatment than the high tungsten types. They are also more brittle when hardened for maximum endurance, and more subject to grain growth when held at the high heats for a long time than are the high tungsten types.

Therefore, when using this method which is a slower heating method and requires holding at a high heat longer, it seems advisable to the writer to use an 18-per cent tungsten steel to obtain the best finished product.

Much less warpage is obtained on thin punches and long slender pieces by this method than any other high-heat method that the author has tried. Small punches, 1/8 inch thick x 3/8 inch wide x 3 inches long, come out straight.

Just a word about clean annealing of hardened work, for tool makers and tool designers occasionally make mistakes, and the die must be reworked. The writer has found that the salt bath is an excellent medium for annealing hardened high speed steel. By heating to 1350 degrees Fahr. (730 degrees Cent.) in a salt bath and allowing to cool in air the die is soft enough to be quite readily reworked and is not scaled.

So far, for a salt bath for tempering and annealing, the author

has used a mixture sold by an eastern firm which freezes at about 1075 degrees Fahr. The small quantity used during a year has not warranted much investigation along this line.

Circular form tools for automatic machines can be hardened by this method and thereby save the expensive operation of grinding. In fact a large portion of my data on dimensional changes of round high speed steel was obtained from circular form-tools and verified by several test bars.

Conclusion

The main difference between the method outlined and the usual open fire method is the use of graphite crucibles in which the work is heated. The method is economical to operate and produces work free from scale, blisters, and pits, with full secondary hardness properties.

Pieces made from round high speed steel stock always expands on the linear dimension and shrinks on the cross sectional dimension when treated by this method.

Pieces made from rectangular high speed steel stock show less dimensional changes than those made from round high speed steel stock.

HEAT TREATMENT OF CAST IRON

By Fred Grotts

Abstract

It has always been considered impractical to heat treat cast iron; also that once cast if the iron was too hard for machining there was nothing to do but send the part to the scrap pile. The purpose of this paper is accordingly to show that the physical properties of cast iron can be very radically modified by suitable heat treatment. Also that the addition of alloys as well as close chemical control of the cupola will give results that are very desirable.

The possibilities in connection with short time malleablizing are discussed as well as the salvaging of defective castings by means of a copper-nickel alloy with the electric arc.

THE heat treatment of cast iron presents some interesting possibilities. By heat treatment is meant the application of heat to such an extent that certain changes in the structure occur which produce desirable physical properties. However, before taking up these points it is best to first discuss some of the metallurgy of this material.

Ordinary cast iron is made in a cupola furnace which is a long cylindrical furnace mounted in a vertical position. It is customary to figure the charge so that a definite final analysis is attained. Not only is this possible for one charge, but for many. For example, it is sometimes necessary to pour several types of castings of various weights, requiring a metal of different composition for the different castings. Also, it is sometimes desirable to pour a chilled iron type, followed, perhaps, by a soft iron one. This is sometimes done by the adding of ferrosilicon to the ladle in sufficient quantities to give the desired results. Silicon has the peculiar ability to prevent or retard the combining of carbon with the iron.

In describing the general procedure and apparatus used for obtaining these general data contained in this paper, a Whiting

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A paper presented before the Chicago chapter of the Society. The author, Fred Grotts, member A. S. S. T., is inspection and metallurgical engineer of the Caterpillar Tractor Co., Peoria, Ill. The data contained in this paper were collected by M. L. Frey, metallurgist, and E. C. Alexander, foreman of the heat treatment department of this company.

cupola with a 48-inch shell and a 6-inch lining, was used. The tuyeres were four in number, 4½ x 7 inches at the back, or narrow side, placed 18 inches above the bottom. Upper tuyeres were provided, but were not used. The slag hole was level with the lower edge of the tuyeres, while the level of the charging door was fifteen feet above the bottom of the cupola.

The air blast was furnished through a 12-inch pipe by a centrifugal compressor having a speed of 3500 revolutions per minute, producing a pressure of six ounces per square inch, measured by an open-end manometer attached so as to show static pressure only.

The coke bed was made up 35 inches above the tuyeres and contained above 960 pounds of coke. The total charge was 1600 pounds of metal with about 160 pounds of coke added between charges.

The melting ratio, with the size of heat shown, was about 10 metal to 1 coke, not including the coke bed. It is possible, with this cupola, to increase the ratio to 11 to 1 and still have hot metal, but with chilled iron production this is not advisable, because in so doing the coke bed is necessarily lowered and less coke is used between charges. This causes the cupola to run more or less under oxidizing conditions, and will burn the carbon out of the metal, and may, in extreme cases, oxidize the iron severely. The result is that the castings crack. As soon as the amount of coke is increased, the castings do not crack and the total carbon of the iron increases. As a rule, the deeper the chill in the casting, the higher will be the total carbon content necessary to prevent cracking. With the depth of chill at present used in the production of truck wheels, the minimum is 3.00 per cent carbon.

The Charge

The metal charge of 1600 pounds is split into two half-charges of 800 pounds each. The constituents are charged as follows:

Coke	Charcoal Pig
Steel	Scrap
Mayari Pig	

Little trouble is experienced with the transition from one mixture to another. Heavy fly-wheels are poured from the iron intermediate to the last of the chilled iron and the first of the

soft iron. Enough ferrosilicon (80 per cent silicon) is added in the ladle to increase the silicon content of the metal about 0.5 per cent.

The flux used is dolomite that will pass through a 2-inch screen, with the fines screened out. Twenty-five to thirty pounds are used to a charge, and is charged on the coke. Under normal operating conditions the slag produced is free-flowing.

Typical analysis of the materials used are:

Mayari Pig:	
Total Carbon	3.20
Manganese	1.30
Sulphur	0.020
Phosphorus	0.028
Silicon	1.96
Nickel	0.73
Chromium	1.84

Charcoal Pig:		Coke Pig:	
Manganese	0.88	Manganese	0.78
Sulphur	0.028	Sulphur	0.022
Phosphorus	0.151	Phosphorus	0.432
Silicon	2.72	Silicon	2.50

The hard iron scrap is the chilled iron returned from the foundry. It consists of gates, sprues, bad castings and rejected material. The soft iron scrap consists of the soft iron returned from the foundry, the gray iron scrap that accumulates throughout the plant, and purchased scrap, which makes up the largest part of the charge. This latter material will contain about 2.25 per cent silicon and 0.045 per cent phosphorus. The steel scrap is miscellaneous in nature. It is obtained chiefly from the machine shop and the rebuilding department. No turnings are used.

The term cast iron as used here applies to any iron in the cast condition which contains so much carbon that it is not usefully malleable at any temperature, even in the annealed condition. It is divided into five types or kinds; namely, gray iron, semi-steel, alloy cast iron, chilled iron and white iron.

Gray cast iron might be said to be the standard cast iron. It is intended for parts that are not subjected to severe shock or tension. When it is used in places where shock occurs it is

necessary to increase the section accordingly. A typical analysis of soft gray iron is as follows:

	Per Cent
Carbon	3.50
Manganese	0.35
Sulphur	0.11
Phosphorus	0.45
Silicon	2.75-3.00

The general physical properties of gray cast iron are low. The tensile strength averages between 18,000 to 20,000 pounds per square inch with a scleroscope reading of 26 to 30. By quenching this material from a temperature of 1550 degrees Fahr. (845 degrees Cent.) a noticeable increase in hardness is observed. In fact, an average of 50 scleroscope has been obtained in treating

Transverse and Hardness Tests

Material		Bar No.	As Cast	Annealed 700° F.	Annealed 1200° F.	Annealed 1500° F.
HEAVY CHILL MIX		1	6670	6530	6000	6180
C. 2.98		2	7000	7325	6790	7780
Mn. 0.52		3	5680*	5750*	6400	6650*
S. 1.11						
P. 0.19		Av.	6835	6927	6396	6980
Si. 1.04						
Cr. 0.62	Scler.		39	39	36	33
Ni. 0.32	Brinell		199	196	187	187
MEDIUM CHILL MIX		1	6220	5420	5825	6400
C. 3.11		2	5870	6225	6825	5450
Mn. 0.76		3	6950	6650	6000	5580
S. 0.114						
P. 0.189		Av.	6346	6437	6216	5810
Ni. 0.52	Scler.		36	35	35	31
Cr. 0.56	Brinell		187	192	170	163
Si. 1.32						
GRAY IRON		1	3600	4000	3700	3770
C. 3.24		2	4200	4650	4000	3800
Mn. 0.96		3	4100	4450	3200	3800
S. 0.150						
P. 0.514		Av.	3966	4366	3633	3790
Si. 2.46	Scler.		31	33	27	25
	Brinell		131	131	92	90

*Indicates faulty bar.

a large number of cylinder heads. It should be observed, however, that when a scleroscope reading of 50 to 60 is obtained it is customary to draw back the hardness to 35 to 45. Care is necessary in treating intricate shapes because quenching cracks are sometimes caused by too rapid and complete quenching.

When castings, such as cylinders and pistons, are taken directly from the foundry to the machine shop, trouble is experienced

from distortion; that is, the parts will almost invariably go out of shape or take odd twists on plain surfaces after quenching. This is due to the relieving of strains that exist in the green castings. To obviate this condition it is common practice to *season* the castings by permitting them to lay for several weeks. Where, however, production will not permit a delay, it is good practice to anneal the castings at a temperature of about 600 degrees Fahr. (320 degrees Cent.). This will relieve strains without undue softening and weakening the material.

Often when close attention is not given to the charges, the analysis will vary so much that hard fins or edges will result on thin section castings. Since these hard spots are due to combined carbon or cementite, a method of annealing is necessary to salvage such castings and avoid tool trouble. Conditions as here mentioned will spoil stellite or high speed tools as fast as they can be supplied. Massive cementite in white iron rapidly breaks down at 1750 to 1800 degrees Fahr. (955-985 degrees Cent.), making a material which is easily machined.

By reducing the silicon content from the above mentioned analysis to approximately 1.30 per cent it is possible to greatly increase the tensile and transverse strength.

Test No.	Total Carbon, Per Cent	Silicon, Per Cent	Tensile Strength, Lbs. Per Sq. In.	Transverse Strength, Lbs.
1	3.10	1.18	31,000	5250
2	3.04	1.30	33,000	5250
3	3.12	1.35	35,000	5300
4	3.06	1.40	42,000	5500

Semi-steel is cast iron, to which steel scrap has been added. The amount of steel scrap varies from 10 to 50 per cent. The addition of steel scrap is for the purpose of increasing the tensile strength, transverse strength and hardness. An average chemical analysis and physical properties of such a material is as follows:

	Per Cent
Total Carbon	3.10
Combined Carbon	0.90
Manganese	0.70
Silicon	1.10
Sulphur	0.09
Phosphorus	0.11
Ultimate Tensile	50,000 lbs. per sq. in.
Transverse	6,500 lbs.
Brinell	175-240

The advantage of semi-steel over ordinary cast iron of equivalent silicon content is that the grain size is smaller, the sulphur and phosphorus contents are lower and the tensile strength is higher. This material resists corrosion better, and has better shock resisting properties than gray iron.

Chilled iron can be produced from low silicon cast iron by pouring the molten metal against a cold surface. This type of material is very desirable from many points of view. It might be likened to case hardened steel; that is, it has a hard surface composed of massive cementite over a less hard background of medium soft gray iron. The chilled surface has a scleroscope hardness of 70 to 80, while the background averages about 38 to 45 and has an average ultimate tensile strength of 40,000 pounds per square inch.

In some castings the chill will affect machinability radically. In order to prevent excessive scrapping of raw material, also trouble from burnt tools, it is our practice to route all castings directly to the heat treating department, where the material is subjected to an annealing operation; that is, the parts are heated to 1750 degrees Fahr. (955 degrees Cent,) for a short time, then the machining operations are performed and the parts are rerouted to the heat treating department for quenching and drawing. This procedure gives a material having a hardness practically equivalent to the original chill but without any tool trouble or loss of material. The physical test of this heat treated material shows a 5 per cent increase in tensile strength over the untreated iron.

Physical Properties of Heat Treated and Non Heat Treated Chilled Cast Iron

No.	Untreated Tensile Strength, Lbs. Per Sq. In.	Treated Tensile Strength, Lbs. Per Sq. In.	Degrees Fahr.
1	21,000	24,000	Annealed at 1750
2	19,500	23,000	Quenched at 1550
3	20,000	25,500	Quenched in oil
4	23,000	22,500	Drawn at 800
Average	21,000	23,000	

It is very important that the complete breakdown of the cementite be accomplished, otherwise quenching cracks will generally result. It has been definitely proven that this reaction is a case of time, temperature and mass. For example, if the heat is applied long enough at 1300 degrees Fahr. (705 degrees Cent.), a complete graphitization is accomplished the same as heating to 1750 or 1800 degrees Fahr. (955-985 degrees Cent.). The time, however, in the latter case is greatly reduced.

It might be mentioned that an exhaustive test was run to determine the best material for certain valve tappets. Among the materials tested were properly heat treated S. A. E. 1020, 2320, 3250, 6150 and chilled iron. The steels in each case showed a checked or roughened surface after 8 hours of running, while the chilled iron retained a perfectly smooth mirror surface. In order to increase the life of the wearing end which was in contact with the push-rod, a cyaniding operation or a simple oil quench was made use of. This gave the required hardness.

Alloy Castings

The subject of alloy castings is a rather broad subject and really should be covered in another paper. The use of chromium, nickel, aluminum and copper have been studied. At present the standard mix contains small amounts of chromium and nickel. Chromium helps the chilling quality of an iron, while nickel seems to retard it. Nickel increases the general hardness and strength. Copper has much the same effect as nickel in amounts up to 1 per cent. Aluminum refines the iron by deoxidation. Nickel gives the best result of all of the alloys tried, as it increases the bending strength materially and the tensile strength about 15 per cent. The castings, while having a good scleroscope hardness, are still machinable. It is of importance to know that a pig iron can be purchased which contains chromium and nickel in varying amounts. Since the alloys are present in the pigs no difficulty is encountered in cupola practice when additions are made.

White Iron Castings

White iron castings find their application as malleable castings after the graphitizing treatment. The item of interest from a heat treatment standpoint is that a white iron can be broken down very quickly by heating to 1800 degrees Fahr. (985 degrees

Cent.), then, by quenching in water and drawing at approximately 1300 degrees Fahr. (705 degrees Cent.) a product is obtained that is readily machinable and has good strength. High ductility, however, is absent, which is one of the essential requirements of high quality malleable cast iron. The application, however, of the above treatment is not intended for maximum malleability, but for a strong intermediate product.

Welding of Cast Irons

The welding of cast irons is always a subject of interest, however, as it has been exhaustively treated by others, only a few points will be emphasized in this paper.

Defects are often found on finished surfaces and in order to salvage these parts, a welding alloy of copper-nickel is used with the electric arc. This weld is readily machinable and has a good bond with the iron. It has good elastic properties which reduces cracking to a minimum. The application of this alloy can be made with the acetylene torch but the electric arc seems to produce more desirable results because the acetylene method of welding requires extensive preheating and high temperatures. It is practical to braze malleable castings as a salvaging proposition.

In summarizing this paper, the following points are predominant:

1. Hard spots in cast iron castings due to combined carbon can be removed by heating to 1750 degrees Fahr. (955 degrees Cent.).
2. There is a certain application for hardening and drawing cast iron.
3. Cast iron to which steel has been added has increased tensile strength.
4. Chilled iron can be softened, then rehardened by heat treatment.
5. White iron can be quickly graphitized by heating to 1750 degrees Fahr. (955 degrees Cent.), then quenching and drawing.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

FACTS AND PRINCIPLES CONCERNING STEEL AND HEAT TREATMENT—PART II

By H. B. Knowlton

Abstract

This article explains the structures and properties produced by cooling plain carbon tool steel at different speeds from above the critical point. The different quenching media are discussed briefly. Some practical advice concerning heating and quenching is given.

The process of tempering or drawing is explained. The effects of different tempering temperatures is discussed. The relative merits of color tempering and tempering in a liquid bath are also discussed. It is brought out that steels of the same hardness may not be similar in their other properties if the hardness is produced by different heat treatments.

IN a previous article,[1] it was shown that when a high carbon tool steel is heated through a certain definite temperature (called the "critical point on heating" or the "Ac point"), the steel loses its magnetic properties, and acquires the ability to harden if quenched. It was also shown that the structure of the steel became very fine grained when the steel was heated to this temperature. Particular emphasis was placed upon the fact that these changes took place at a certain definite temperature, which is called the critical point. It was further shown that quenching this kind of steel from temperatures still higher above the critical point did not produce any greater hardness but did make the steel more brittle. The higher the steel was heated the more brittle it became after quenching. In short it was shown that the best combinations of

[1]The first installment of this series of articles appeared in the March, 1925, issue of Transactions.

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hardness, toughness and fine grain could be produced only by heating this steel to just above the critical point and quenching it. Therefore, it would follow that a knowledge of the critical point of a tool steel should be of great value to the practical hardener.

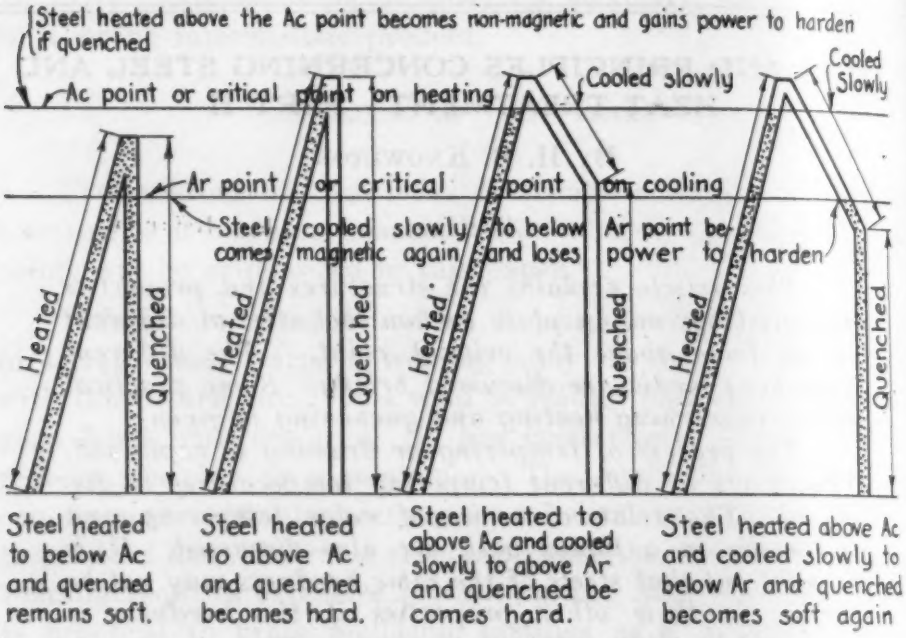
Steel heated above the Ac point becomes non-magnetic and gains power to harden if quenched
Ac point or critical point on heating
Cooled slowly
Cooled Slowly
Ar point or critical point on cooling
Steel comes magnetic again
cooled slowly to below
Ar point be and loses power to harden
Heated
Quenched
Steel heated to below Ac and quenched remains soft.
Steel heated to above Ac and quenched becomes hard.
Steel heated to above Ac and cooled slowly to above Ar and quenched becomes hard.
Steel heated above Ac and cooled slowly to below Ar and quenched becomes soft again

Fig. 1—Diagram Showing the Effect of Different Heating and Quenching Treatments on the Properties of High Carbon Steel.

Similarly it was shown that when a high carbon tool steel which has been heated above the Ac point (critical point on heating), is allowed to cool slowly it does not lose its hardening power or regain its magnetic properties until it reaches another certain temperature which is called the "Ar point" or the "critical point on cooling". The Ar point is not the same temperature as the Ac point, in fact the Ar point is usually from 70 to 100 degrees Fahr. lower than the Ac point. So, while it is necessary to heat an ordinary high carbon tool steel to 1380 degrees Fahr. (750 degrees Cent.) or above to harden it, once it has been heated to this temperature, it does not lose its power of hardening until it has cooled to 1250 degrees Fahr. (650 degrees Cent) or below. This point is also of practical value to the hardener, and will be referred to again. With the indulgence of the reader, the diagram representing these changes is repeated, as it may make some of the present article a little more clear. See Fig. 1.

It is natural for one to wonder why certain changes take place. It is usually true that a knowledge of why things happen is of real practical value in solving new problems. On the other hand, attempts to reason out why certain changes take place, sometimes leads to the forming of assumptions and speculations which one person can not prove and his opponent can not disprove.

So it has been with the hardening of steel. For years there has been much discussion as to why steel hardens. Many theories have been offered. However, there is still room for differences of opinion. All of the authorities do not agree. When it is finally determined and proven just why all of the actions in hardening, tempering, and annealing, take place, it is probable that we will be in position to do much better heat treating. In this article, we do not wish to go into the discussion of any of these theories of hardening. There are, however, some facts about hardening and heat treating which have been established and we will devote a little time to the consideration of some of these scientific facts, as they are of practical value in the consideration of commercial heat treating problems.

The use of the microscope has brought out some of the most interesting and valuable scientific facts concerning the changes which take place in steel during the heat treating operations. This is not a matter of theory or speculation. The differences in the structures can actually be seen when the steel is examined with a microscope.

It will not be possible in this article to give a thorough discussion of microscopic structures, because the microscopic study of steel is a big subject in itself and it would be impossible to do it justice in a few pages. However, a few photomicrographs are presented in order to show the reader that there really is a considerable difference in the structure of steel after different heat treatments, and that these structures are well worth studying.

Fig. 2 shows the structure of an 0.85 per cent carbon tool steel in the annealed condition. This is the structure which metallurgists call "pearlite." When this steel is heated to the Ac point (critical point on heating) it not only loses its magnetic properties, and acquires the power of hardening, but its entire structure changes. If it were examined under the microscope while heated above the critical point, it would show the structure

represented in Fig. 3. This structure is called "austenite" in honor of Sir Roberts-Austen an English metallurgist who accomplished a great deal in the study of steel and iron at high temperatures.

All steels when heated to above the critical point are changed into austenite. When in this condition all steels are somewhat alike. They would all show much the same microscopic structure as shown in Fig. 3. On the other hand, the different steels in the annealed condition show quite different microscopic structures. It will be noted that austenite as shown in Fig. 3 seems to be made up of irregular grains or crystals of the same substance, while in Fig. 2 which shows tool steel in the annealed condition there seems to be at least two constituents present, one of which appears darker than the other.

The explanation of this is that when steel is heated to above the critical point, the iron and carbon form a solid solution. To the man who has not studied metallurgy the idea of a solid solution may be somewhat new, and yet solid solutions are not uncommon. They are similar in many respects to the liquid solutions with which we are all familiar. They can probably be best explained by comparing them with liquid solutions. When salt is dissolved in water, a liquid solution is formed. Such a solution looks like clear water. Even if a drop of the solution is examined under a high power microscope, it is impossible to see any particles of salt in it. When the grains of salt were dissolved, they were broken up into particles which are too small to be seen even with a microscope. It is possible to have much or little salt in the solution, or as it is sometimes expressed, the solution may be concentrated or dilute. If the solution is stirred up, the salt will be evenly distributed throughout the solution. On the other hand, if the salt is dropped into a glass of water and not stirred up, it may be possible at least at first, for the solution at the bottom to be more concentrated than the solution at the top. If a dilute salt solution is frozen, a block of ice is formed in which no particles of salt can be seen. The salt is still dissolved. It would still be impossible to see the salt even with a microscope. Such a solution is called a solid solution. This may explain the nature of a solid solution.

So, it may be said that when steel is heated to above the critical point, a solid solution is formed. The only difference is that

in this case the solid solution is formed directly without a liquid solution being formed first. This solid solution may contain small or relatively large amounts of carbon, manganese and other elements dissolved in the iron. Like most solutions there is a limit to the amount of carbon which may be dissolved, and also like most solutions the limit of solubility varies with the temperature. When the solid solution, or austentite, is examined under the microscope, it is seen that it is composed of crystals. These are not crystals of iron or carbon but of the solid solution itself. When the steel is heated to just above the critical point the austenite crystals formed are very small. When heated to higher temperatures these crystals grow larger. The higher the steel is heated the larger the crystals become. The length of the time of heating also has an effect upon the size of the crystals, although even a few minutes at a white heat will produce larger crystals or grains than several hours just above the critical point. This may explain the reason that the fracture of over-heated steel is always coarse grained.

The fact that the heating of steel to above the critical point is really a process of forming a solid solution, is of great practical importance. All annealing, hardening and other heat treatments which seek to refine the grain must proceed by first forming a solid solution, and many of the commercial heat treating failures are due to the fact that a perfect solution was not formed. Forgings, castings and other parts which have cooled from high temperatures, and which are consequently coarse grained, must frequently be held at some temperature above the critical point for considerable time in order to form a complete solution, just as it takes longer to dissolve larger crystals of salt than it does small ones. Again the higher the temperature the faster the solution will be formed. In the case of fine grained steels it is not so difficult to form the solid solution.

Effect of Speed of Cooling From Above the Critical Point

The hardness of high carbon steel is greatly affected by the rate of speed with which it cools from above the critical point. In explaining the effects of the different cooling speeds, an 0.85 per cent carbon steel will be considered because this presents the simplest condition. (Carbon steel having a carbon content of 0.85 per cent is commonly used for cold chisels and other tools requiring a hard cutting edge and resistance to shock.)

As already stated, when such steel is heated to above the Ac point (critical point on heating) it becomes austenitic or a solid solution. When it is allowed to cool from above this point, no change takes place until it reaches the Ar point (critical point on cooling). At this point, if the cooling is slow, the austenite begins to break up and change back into ordinary annealed steel. This change can not be made instantaneously. In fact the change back to soft steel involves several different steps. The microscope proves that there are at least four of these steps in the change from austenite back to annealed steel or pearlite such as shown in Fig. 2. The steps or stages in the transformation from austenite to pearlite, are called martensite, troostite, and sorbite.[2] The structures of martensite, troostite and sorbite are shown in Figs. 4, 5, and 6. (These photographs are presented for the purpose of showing that there really is a difference in the structure. It will not be attempted to give a technical discussion of the different structures.)

All of these changes require time. As they are changes in the internal structure of the steel, they can take place only while the steel is hot. It has been noted that some slight changes in the properties of steel may take place after the steel is cold, but these changes are not great enough to make any marked difference in the structure of the steel as observed under the high power microscope. As a general rule it will hold that most of the changes in the structure of steel must take place while the steel is hot. It must follow, therefore, that if the steel is to be changed from austenite to pearlite that plenty of time must be allowed for all the changes to take place before the steel becomes cold. These changes begin as soon as the steel has cooled to the Ar point. It is not possible to give any definite temperature below which no change takes place. At temperatures only a little below the Ar point the changes take place fairly rapidly. At lower temperatures the changes take place slower and slower until finally at room temperature (70 degrees Fahr.), they practically do not take place at all. Pearlite may be produced either by very slow cooling all the way from the critical point down to ordinary room temperature or by cooling to to a little below the Ar point and then holding at that temperature long enough to allow all the changes to take place. After this has been accomplished the cooling may be faster.

[2]These names have been given in honor of Martens, Troost and Sorby.

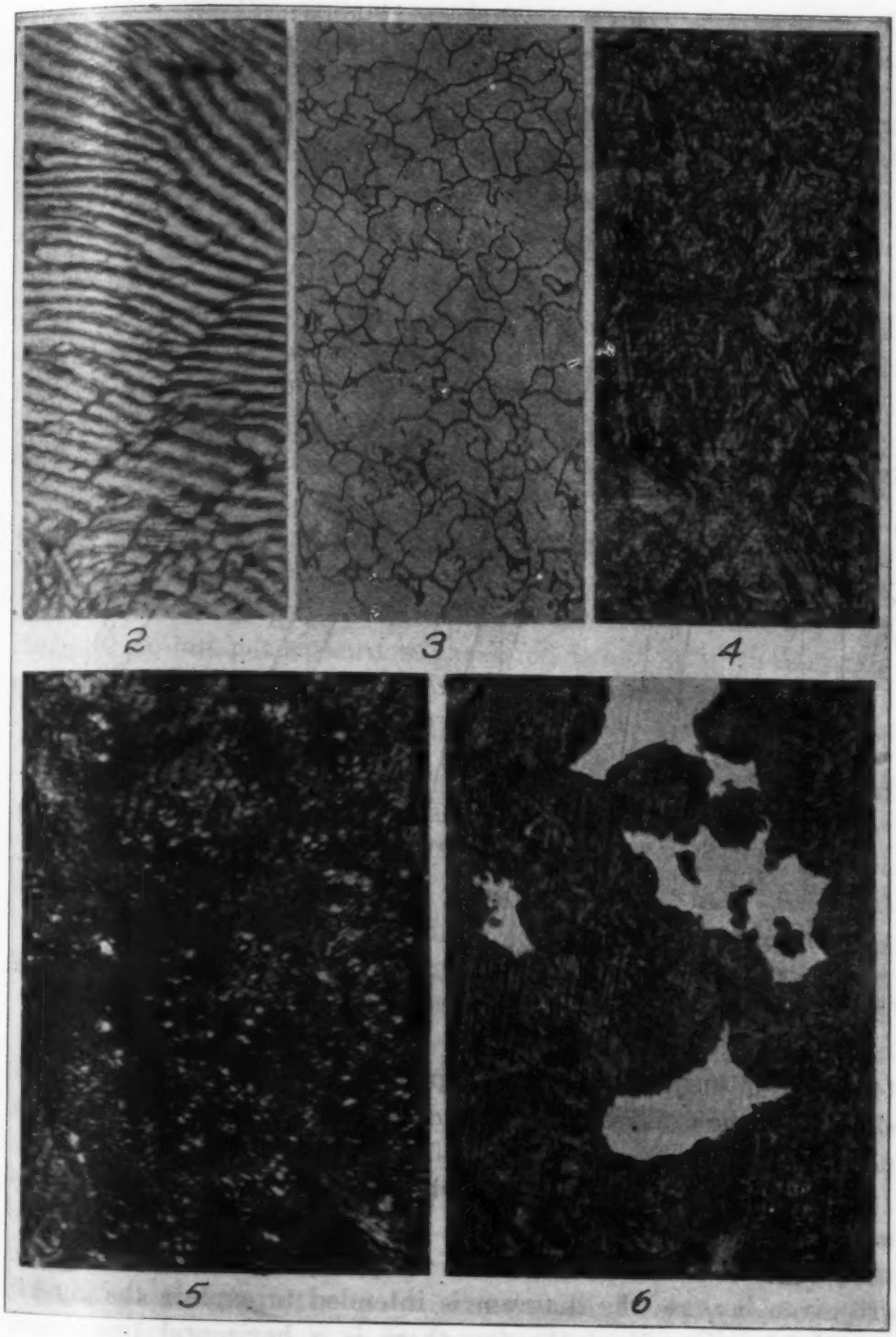

Fig. 2—Photomicrograph of Pearlite. 2000x. Fig. 3—Photomicrograph of Austenite. 200x. Fig. 4—Photomicrograph of Martensite. 500 x. Fig. 5—Photomicrograph of Sorbite. 200x. Fig. 6—Photomicrograph of Martensite (light) and Troostite (dark). 500x.

Explanation of Hardening

Steel is hardened by rapid cooling from above the critical point. Such rapid cooling does not allow time for all the changes from austenite to pearlite to take place before the steel becomes

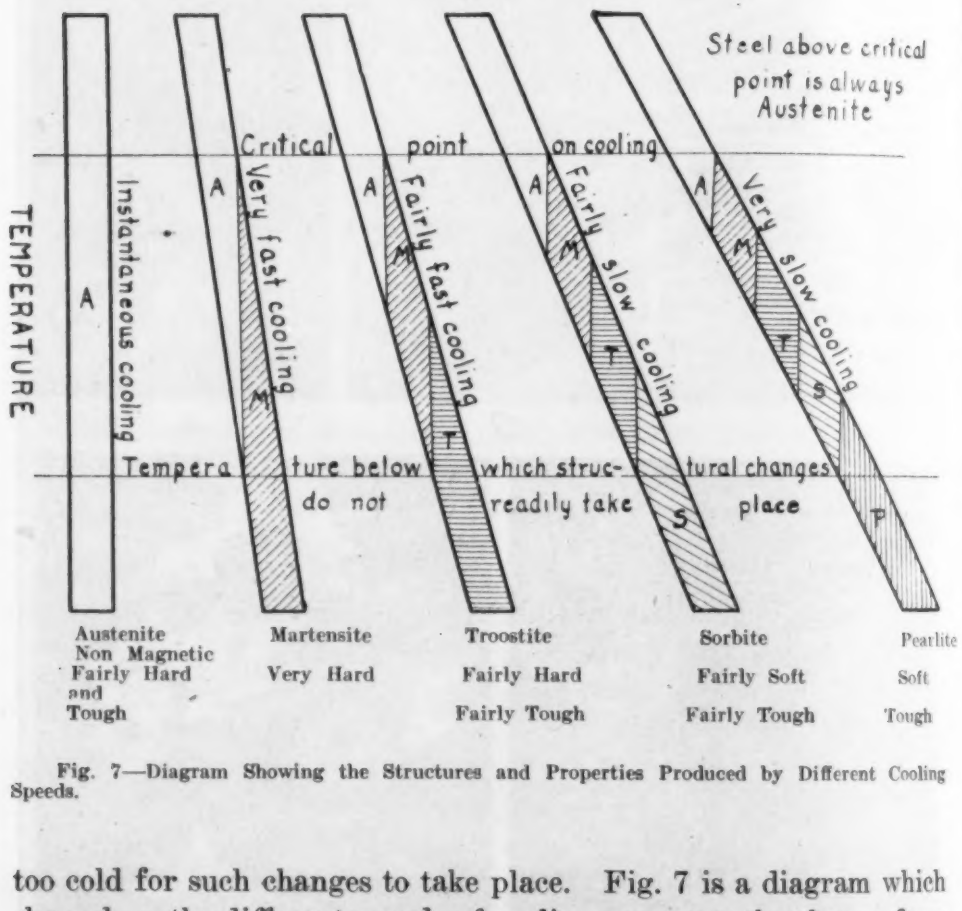
Steel above critical point is always Austenite
Critical point on cooling
TEMPERATURE
A
Instantaneous cooling
Very fast cooling
Fairly fast cooling
Fairly slow cooling
Very slow cooling
Tempera ture below which struc- tural changes do not readily take place
Austenite Non Magnetic Fairly Hard and Tough
Martensite Very Hard
Troostite Fairly Hard Fairly Tough
Sorbite Fairly Soft Fairly Tough
Pearlite Soft Tough

Fig. 7—Diagram Showing the Structures and Properties Produced by Different Cooling Speeds.

too cold for such changes to take place. Fig. 7 is a diagram which shows how the different speeds of cooling may stop the change from austenite to pearlite in any one of the steps of the transformation. In this diagram the vertical distances have been used to represent temperatures, while the horizontal distance represents the time of cooling. No definite temperatures or periods of time are given because the diagram is intended to explain the general principles only. Near the top there is a horizontal line drawn across the diagram which represents the critical point on cooling (Ar point). Near the bottom there is another horizontal line to represent the temperature below which structural changes do not

readily take place. It must be remembered that this is not an exact temperature like the critical point, although for convenience of plotting it is represented as such. It is assumed that the steel has already been heated above the Ac point (critical point on heating) and is consequently in the austenitic condition. The diagram shows what happens when steel in this condition is cooled at different speeds.

Instantaneous Cooling

The left hand figure represents what would happen if it were possible to cool the steel instantaneously, that is in zero time. If this were possible, the austenite would remain unchanged after cooling. As a result the steel would be austenitic after it was cold. It is not possible in the case of the ordinary plain carbon steels to cool fast enough to prevent any change from the austenitic condition. However, in the case of some of the high alloy steels it is possible to produce austenite in the cold, and it is to these steels that we owe a large portion of our knowledge of the properties of austenite. A steel in the austenitic condition is non-magnetic, fairly tough, but not as hard as the same would be in the martensitic condition.

Very Fast Cooling

The second figure from the left (Fig. 7) shows the result of very rapid cooling. As soon as the steel cools below the Ar point it starts to change to martensite. As the cooling continues, more and more of the austenite changes into martensite until finally it is entirely changed into martensite. This figure represents a speed of cooling which would allow the austenite to entirely change into martensite, but which would prevent the martensite from undergoing any change, i. e., by the time the steel was changed into 100 per cent martensite, it would be below the lowest temperature at which changes take place. In the case of ordinary plain carbon tool steels this would mean rapid cooling, such as quenching in cold water.

Martensite is the hardest condition in which steel exists. There is a difference in the maximum hardness which can be attained by different steels, but in the case of any one steel it may be said that it is the hardest when it is in the martensitic condition. Tools which require great hardness are usually heat treated so as to produce the martensitic condition.

Fairly Fast Cooling

The third figure from the left in diagram (Fig. 7) shows that when the steel is cooled a little slower it has time to change first to martensite and then to troostite, before it becomes too cold to permit further change. The resulting structure is troostitic. In this condition steel is fairly hard but not as hard as in the martensitic condition. Troostite, however, is somewhat tougher than martensite. In the case of plain carbon tool steels, fairly fast cooling is necessary to produce this condition.

Fairly Slow Cooling

The fourth figure from the left in Fig. 7 shows that when the steel is cooled slowly it makes three steps of the change before it becomes too cold for further change. The resulting structure is sorbitic. This is not usually considered as a hard condition although it is somewhat harder than pearlite or fully annealed steel. In this condition steel is quite strong and tough.

Very Slow Cooling

The figure on the extreme right (Fig. 7) shows that when steel is cooled very slowly it has time to pass through all the stages of the transformation and become entirely pearlitic before it becomes too cold to undergo change. When a steel is in the pearlitic condition it is soft and machinable. It is also quite tough but not as strong as when it is in the sorbitic condition.

Mixed Structures

It frequently happens that the speed of cooling is such that more than one of these structures appears in the steel after cooling. The resulting structure may be a mixture of martensite and troostite, or troostite and sorbite or sometimes a mixture of all three. When large tools are quenched it is obvious that the outside will cool much faster than the center, so it is possible for the outside layers to be largely or entirely martensitic, while the center may not contain any martensite. Figs. 4, 5 and 6 all show mixed structures. Fig. 4 shows the structure of a cold chisel after water quenching which consists mostly of martensite at the edge while Fig. 6 shows more troostite a little deeper in the same chisel.

The foregoing explains the changes which take place when an 0.85 per cent carbon tool steel cools from above the critical point. The same general principles apply in the main to all steels. In the

case of steels containing less than 0.85 per cent carbon there is more than one critical point, both on heating and on cooling, and the actions are a little more complicated than those just described. This will not be discussed at this time. The explanation of changes in 0.85 per cent carbon steel will also hold for the ordinary plain carbon tool steels containing more than 0.85 per cent carbon, providing they are not heated far above the Ac critical point. At higher temperatures there is still another action which takes place.

Before leaving this discussion it should be said that while the same types of structure may be produced in all the plain carbon tool steels, it is not to be assumed that the properties of different steels will be exactly the same if they have similar structures. For example, two steels of different carbon content may both be martensitic and not be the same hardness. The one which is the higher in carbon will probably be the harder. With these points in mind we may well proceed to the discussion of practical hardening of the plain carbon tool steels.

Hardening Plain Carbon Tool Steels

From the foregoing discussion it is apparent that the hardening of plain carbon tool steel (steel containing from 0.70 to 1.40 per cent carbon) must consist of heating to above the Ac (critical) point long enough to produce complete solid solution (austenite) followed by a rate of cooling which is fast enough to prevent the austenite from changing to one of the softer constituents (sorbite or pearlite). In the present discussion it will be assumed that the steel has been received from the mill in the best condition for hardening. The annealing, normalizing and spheroidizing treatments which are sometimes necessary to put the steel in the best condition for hardening will be considered later.

Hardening Temperature

It has already been brought out that the greatest hardness, the finest grain, and the greatest toughness (in the hardened condition) can only be produced by heating the steel to just above the Ac point. The higher the steel is heated above this point the coarser its grain becomes and consequently the more brittle is the product. On the other hand, if the temperature of the heating is below the critical point the steel will not harden at all. In practical work it is seldom if ever attempted to quench steel from the theoretical Ac, or critical point. It is the usual practice to heat the steel 50 to 75 degrees

Fahr. (and sometimes higher) above the critical point.

The critical points of steels containing from 0.85 to 1.40 per cent carbon are all about 1350-1320 degrees Fahr. The usual hardening range is 1430-1380 degrees Fahr. The Recommended Practice Committee of this Society gives the following recommendations:[3]

	Heat Treating			
Carbon Range, per cent	0.65-0.80	0.81-0.95	0.96-1.10	1.11-1.25
Hardening Temperature °F.	1550-1450	1460-1410	1390-1430	1380-1420
Quenching Medium and Its Temperature	Water at 70 Degrees Fahrenheit	Water at 70 Degrees Fahrenheit	Water at 70 Degrees Fahrenheit	Water at 70 Degrees Fahrenheit

It will be noted that the temperatures given for quenching are higher for the tool steels of the lower carbon content. This is good standard practice. The reasons for raising the quenching temperature in the case of steels containing less than 0.85 per cent carbon will be considered later.

It is impossible to give a definite quenching temperature which will produce the best results on all tools made of the same kind of steel. In general it may be said that the larger pieces should be quenched from higher temperatures than the smaller ones. The recommendations just quoted do not mean that any temperature between the limits stated will produce the best results. It may better be stated that the best quenching temperature for any particular tool probably lies between the limits given. In the end it is necessary for the individual hardener to experiment and determine just what temperature produces the best results for each tool which he has to handle. In some instances it may even be necessary to use temperatures outside the limits given. The recommendations hold as a general rule, and it may be well to caution the hardener against wide variations from the practice recommended until he has experimented very carefully and has conclusively proved that he is right. It is doubted if the wide variations in quenching temperatures which are found in some hardening rooms can be justified. When the best temperature for hardening any

[3]Recommended Practice in the Heat Treatment of Plain Carbon Tool Steel, A. S. S. T. Handbook, pages N-3 to N-6.

particular tool has been determined, it is well to always harden that tool from the exact temperature as accurately as possible.

Measuring the Hardening Temperature

If all tools are to be heated to exact temperatures, it is necessary that there be some means of measuring the temperature accurately. There are on the market a number of good *pyrometers,* which will measure temperature to within at least 10 degrees Fahr. In fact it is possible to obtain a certificate of their accuracy from the U. S. Bureau of Standards. Nearly all modern hardening rooms use pyrometers for measuring temperatures for annealing, hardening and heat treating, but there are still some hardeners who believe that it is well enough to rely upon their eyes for judging temperature. It is true that a good hardener should be able to judge the temperature between red and white heats fairly accurately by eye. It is also true that an experienced draftsman can lay out an inch fairly accurately without the use of a scale and that a machinist can judge the thickness of a piece of paper or a thin piece of metal by feeling it, but no draftsman or machinist would recommend discarding scales, micrometers and other measuring instruments. Where accurate work is to be done the pyrometer is just as necessary for measuring temperature as the scales and micrometers are for measuring distance. At the same time there is no pyrometer system which is actually "fool proof." Pyrometers are delicate instruments and they must be installed and maintained properly. It will not be possible in this article to give a complete discussion of pyrometers. It may be briefly stated that the type of pyrometer system which is most commonly used in the hardening room consists of a *thermocouple,* one end of which is placed in the furnace, a meter (either potentiometer or galvanometer) which indicates or records the temperature, and wires connecting the two. The thermocouple when heated generates a current, the strength of which depends upon the temperature, and the meter measures the strength of the current. It is arranged so that it will indicate the temperature of the furnace. (For the principles of the pyrometer the proper installation compensation for "cold end" temperatures, checking of pyrometers, etc., see A. S. S. T. Handbook, pages S-3 to S-17.

It is not sufficient that the meter indicates the proper hardening temperature. This shows only that the thermocouple in the

furnace is at the desired temperature. It is necessary that the hardener be sure that the tool to be hardened is at the same temperature as the thermocouple. This may be done by comparing the color of the tool with that of the thermocouple. When the couples are installed properly and a standard practice of operating the furnace has been worked out it may be possible to run entirely by the temperature as shown by the thermocouple and the length of time the tool is in the furnace. However, it is well for the hardener to use his eyes and his brain just the same.

Speed and Uniformity of Heating

The speed and the uniformity of heating are among the most important factors in successful hardening. Too rapid or non-uniform heating may cause cracking when the steel is hardened. When steel is heated it expands. If a large piece is heated very rapidly the outside will become hot much faster than the center and the result will be that the outer layers will attempt to expand and pull away from the center. This places the steel under a strain which may result in cracking when it is quenched. Obviously the larger the piece the greater the danger will be. Similarly when heating a tool which has both thick and thin sections there is danger of the thin sections heating faster than the thick ones, thus causing strains. The damage done by rapid and uneven heating is probably the greatest at the start of the heating, while the center of the piece is still cold and rigid. After the whole piece is hot enough to be more or less plastic, it is possible for it to yield a little and the danger is not so great. It is good practice to at least warm all tools before placing them in a hot furnace. In some hardening rooms two furnaces are used. One of these is run at a comparatively low temperature and the tools are preheated in this furnace before being placed in the final heating furnace. This is the most common practice in hardening high speed tools, but is not so common in hardening plain carbon tool steels. Very large pieces such as drop hammer die blocks should never be placed in a very hot furnace. It is better to heat them up with the furnace.

It will not be possible to discuss all the methods which have been employed for producing slow and uniform heating. Lead pots and salt baths which heat the tool from all sides at once, continuous heat furnaces in which the steel is slowly fed through the furnace, "hump" furnaces, and other devices all have their merits. Let

it be said that the hardener should employ some method to heat the steel as slowly and uniformly as is commercially practicable. The larger the tools the more carefully they should be heated.

Another dangerous period in the heating of the steel is while it is passing through the critical range. As has been stated before, when steel reaches the critical point on heating, it contracts a little instead of expanding. If the entire tool reaches the critical point at the same time there is not much danger, but when one part of the tool reaches the critical point ahead of the rest, it is obvious that this part of the tool will be contracting while the rest is expanding. This difference in the action of the various parts of the tool at the same time causes strains which may result in cracking. Again the danger is much greater in the case of very large tools.

Quenching Plain Carbon Tool Steel

It follows from the previous explanation of what happens in the hardening of plain carbon tool steel, that in order to produce hardness it is necessary to cool rapidly from above the critical point. The greatest possible hardness will be produced when the speed of cooling is fast enough to produce 100 per cent martensite. If the cooling is still faster some austenite may be produced, which is not as hard as martensite. However with the ordinary plain carbon steels there is little chance of ever producing austenite with any ordinary method of cooling. If the cooling is not fast enough to produce 100 per cent martensite, it may be expected that there will be some troostite present, which is not as hard as martensite.

The selection of the proper bath for quenching steel depends upon the speed with which the bath will cool the steel. Water cools steel faster than oil, and brine produces faster cooling than water. The material used for quenching is called the "quenching medium". (The plural of medium is "media." Sometimes the word "mediums" is used.) A great deal of work has been done in the study of quenching media. Several excellent articles have appeared in Transactions on this subject. These will not be discussed in detail in this article. Several years ago, Mathews and Stagg published their results of some experiments which show the cooling speeds of different media.

In performing these tests a suitable sized piece was heated to 1200 degrees Fahr. and was then quenched in a bath containing 25 gallons of the quenching medium to be tested. The time

in seconds required for the piece to cool from 1200 to 700 degrees Fahr. was measured with a stop watch. As the piece cooled down, the quenching bath of course became warmer. The rise in the temperature of the quenching bath was also measured. The

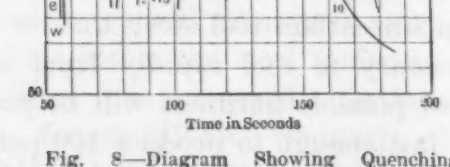

Fig. 8—Diagram Showing Quenching Speeds of Different Media. (Mathews and Stagg.)

test was then repeated quenching the test piece in the bath which had thus become warmer. This operation was continued until the bath either reached its boiling point or 250 degrees Fahr. The results are shown in the accompanying diagram, Fig. 8.

While on the subject of quenching media, a few words with regard to what actually happens during quenching may not be out of place. When a piece of hot steel is immersed in the quenching liquid (water, oil or salt solution) it causes the liquid touching the steel to be raised to the boiling point and then to boil. The steam or vapor thus produced may be condensed before it reaches the top of the quenching tank, but this does not affect the action so far as the steel is concerned. It follows that heat is taken away from the steel in two ways. First in raising the temperature of the liquid to the boiling point and second in boiling it. It requires 142 B. t. u. (British Thermal Units) to raise the temperature of 1 pound of water from 70 to 212 degrees Fahr., but it requires 970 B. t. u. to convert 1 pound of water at 212 degrees Fahr. into steam, so it will be seen that most of the

heat is used in performing the boiling. This may explain the reason that water cools steel faster than oil in spite of the fact that it has a lower boiling point.

As soon as the liquid around the steel is changed into steam or vapor, it rises toward the top of the tank and more cool liquid flows against the steel. The speed of the quench, therefore, depends in part upon the ease with which the quenching liquid flows. This is called the viscosity. Liquids which are "thick" and flow very slowly are said to have a high viscosity. If a piece of hot steel were quenched in a tank of cold tar, we would not expect very fast cooling. The tar touching the steel would be boiled away, but fresh tar would not flow in rapidly to take its place. To a less extent the same is true of thick heavy oils. Most oils are thinner and more fluid when they are warm. This explains the reason that some oils cool steel faster when they are warm than when they are cold.

Another factor governing the quenching speed is the heat conductivity of the quenching liquid. Heat is not only carried from one part of the quenching tank to another by circulation of the quenching medium, but is *conducted* through the bath without any motion or circulation of the liquid. Water and oil, however, are poor conductors of heat, and the amount of heat which is taken away from the steel by conduction through the quenching bath is comparatively small. Mercury, on the other hand, flows slower than water but conducts heat faster.

It will be seen therefore that cooling by quenching is a rather complicated action involving the following factors:—(1) the temperature of the bath; (2) the quantity of heat required to raise a given amount of the quenching medium 1 degree (specific heat), (3) the amount of heat required to change a given amount of the medium into steam or vapor at its boiling point (latent heat of vaporization); (4) the conductivity of the medium; and (5) the fluidity (or viscosity) of the medium. There is, however, no mysterious action connected with the quenching of steel. The time is not long past since it was common to find hardeners with complicated, mysterious, and usually secret formulas for quenching baths which were supposed to have some magic action.

The speed with which the quenching medium comes into contact with the steel can be greatly increased by forced circulation.

In some hardening rooms when it is desired to produce very rapid cooling, the steel is cooled by a high pressure spray instead of by immersing the steel in a tank of water. On production work it is possible to arrange a number of jets so that the tool will be attacked on all sides at once by streams of water. When this method is used the tool is placed in position before the water is turned on. When the main water valve is opened the water shoots through all the jets at once and thus cools the steel uniformly. By using high pressure water it is possible to have a very large volume of water pass over the steel in a short time. This can be arranged to produce faster cooling than can be accomplished by immersing the steel in a tank of ice cold brine.

The Recommended Practice Committee of the A. S . S . T. advises the use of water for the quenching of most carbon steel tools. This has many practical advantages, as water is cheap, and requires no storage tanks. A wide range of quenching speeds can be obtained by varying the speed of circulation of the water, by the use of special quenching fixtures such as mentioned above, and by varying the temperature. In very small hardening rooms a tank of brine may find some use. Quenching in still brine produces faster cooling than quenching in still water, but when a great many pounds of steel have to be quenched in a day, the brine will become hot and the speed of cooling will be decreased unless some provision is made for cooling the brine or circulating it between the quenching tank and the large storage tank.

The use of oil as a quenching medium is highly advised for some kinds of steel but in the case of tools made of plain carbon steel, it is usually better to use water. There may be some jobs for which oil will be more advisable. The advantage of an oil quench is that the speed of cooling is slower and there is less danger of warping and cracking. An oil should be selected which has the desired quenching speed. It is obviously wise to use an oil which will not catch fire easily. It is also preferable to use an oil which will not be greatly changed in composition by repeated use. It is important that the cooling be as uniform as possible. Cooling one part ahead of another usually results in warping or cracking. Long thin pieces are usually held vertically during quenching, as this makes the cooling more uniform and reduces the danger of warping. It is possible, however, in the case of some

round articles to quench horizontally and still produce uniform cooling by keeping the steel spinning. For example, a round bar may be rolled down rails through the quenching tank. As long as the bar is rolling over and over all sides get the same conditions of cooling.

When tools are held by hand tongs, it is well to keep them moving during the quenching. This cannot always be done in the case of large heavy pieces which cannot be held by the hardener. In such cases the quenching medium is often circulated more rapidly by pumps, or is agitated by blowing air into the tank.

While discussing uniform cooling it is well to mention that a tool should never be quenched while one part appears to be hotter than another. (This does not apply to cold chisels, shank tools, and other articles which are not to be hardened all over). Some hardeners hold the tool in the tongs for a few seconds after removing from the furnace before quenching, if the thin sections appear any different in color from the body of the tool. It must be remembered that the Ar point (where the steel begins to change back to the soft condition) is considerably below the Ac point above which the steel was heated. This allows the temperature to even up before quenching. If the steel has been properly heated this may not be necessary. Care should be taken that the tongs do not touch the cutting edge of the tool. Preheating the tips of the tongs is good practice. Milling cutters and similar shaped tools may well be held by a hook passing through the hole of the tool.

Cracking usually takes place after the tool is cold. For this reason it is best to remove the tool from the quenching tank before it becomes entirely cold. A common recommendation is to remove it as soon as it cools below the boiling point of water. If the tool is held with hand tongs, this is an easy point to determine. As long as the steel is causing the water to boil, a vibration of the tongs can be felt. When this stops the steel is below the boiling point of water and should be removed.

As soon as the steel is removed from the quenching tank it should be tempered or drawn. If it is allowed to become cold and stand around it is more likely to crack.

Tempering of Plain Carbon Tool Steel

As just stated all tools of plain carbon tool steel should be

tempered or *drawn* immediately after hardening. The word temper means to moderate or make less extreme in properties. For example when it is said that we live in a temperate climate it is meant that the temperature here is not as cold as it is at the North Pole nor as hot as it is at the Equator. So to temper hardened steel means to make it a little less hard and brittle.

The words "tempering" and "drawing" are used for the same process. The word drawing is used to mean the taking or drawing of some of the hardness and brittleness out of steel. Possibly the original idea was that some material thing was actually drawn out of the steel. We know that this is not the case. The chemical composition of the steel remains the same. However the term drawing is still in common use.

Process

The tempering or drawing process consists in reheating hardened steel to some temperature below the critical point. Plain carbon steel tools are seldom tempered higher than 600 degrees Fahr.

Effects of Tempering

When a hardened steel is tempered three actions may take place.

1. The strains are relieved
2. The steel is toughened
3. If the temperature is above 400 degrees Fahr. the hardness and strength of the steel are reduced. The higher the tempering temperature, the softer and tougher the steel becomes.

These actions will be discussed in order.

Strains

It may be difficult to get a mental picture of steel being under strain. Similarly it is difficult to measure the strains, and yet the effect of strains is often very apparent. When a piece of hardened steel cracks or breaks without being touched, it is evident that the damage is done by some internal force. This is not an uncommon occurrence. In fact large tools have been known to break with such force that one part actually flies off from the main body of the tool. This is due to the internal strains.

The causing of strains by too rapid or non-uniform heating has already been discussed. While this danger may be avoided

by more careful heating, it is impossible to avoid rapid cooling and still produce hardness in a plain carbon steel. When a hot tool is immersed in the quenching bath it is obvious that the heat is absorbed from the outside of the tool. This means that the outside must cool faster than the center. Consequently the outer layers of the tool contract while the center tends to stay in the expanded condition. Later when the center cools down, it contracts and pulls away from the outer layers. This action is more pronounced in the case of large pieces, because of the greater difference in the temperatures of the surface and the center, during quenching.

The tempering or drawing of steel relieves these strains, and removes the danger of the tool cracking or breaking of its own accord. As has already been stated, cracking usually takes place after the steel is cold. It follows, therefore, that the tool should be withdrawn from the quenching tank before it is entirely cold and should be tempered immediately.

As strains are not easily measured, it may not be easy to state a definite temperature for relieving of strains. Heating to the boiling point of water probably relieves strains to some extent, but higher heating is safer. When it is desired to relieve strains without producing any softening action, it is the common practice to temper at the highest temperature which can be used without producing softening. The Recommended Practice Committee of the A. S. S. T. advises temperatures from 350 to 375 degrees Fahr. when relieving strains is the only objective of tempering.

Toughening

When a high carbon steel is hardened it becomes brittle, i. e., it will not stand bending or any other change of shape without breaking. It is also easily broken by shock. Tempering decreases the brittleness, or in other words toughens the steel. The higher the steel is tempered or drawn, the tougher it becomes. The toughness may be determined by measuring the number of degrees a certain size bar will bend without breaking. Consequently, the tempering temperature depends upon the amount of toughening which is required. The Recommended Practice Committee gives the following advice.—

Results desired	Tempering Medium	Temperature Degrees Fahr.
Relieving Strains	Oil	350-375
Strain relieving and Reduction of Brittleness	Oil	400-500
To relieve Strains and Toughen	Oil	500-600

Here the terms "reduction of brittleness" and "toughening" are used to describe different degrees of the same action. As stated before, the higher the tempering temperature, the greater the action will be.

Softening

Plain carbon tool steels are not tempered for the purpose of softening. A softening action, however, takes place during tempering. The amount of the softening is very small if the tempering temperature is below 375 degrees Fahr. In fact, so far as commercial results are concerned it may be said that there is practically no softening action before the steel reaches a temperature of about 400 degrees Fahr. The higher the steel is heated above this temperature, the greater the softening action becomes. The question for the heat treater to decide is often; how much hardness may be sacrificed in order to produce the necessary toughness. This will be different in the case of different tools. For example, a lathe tool, which requires a very hard cutting edge, but does not have to stand shock, should be given a low tempering treatment probably not over 375 degrees Fahr. On the other hand, a cold chisel which must have a fairly hard cutting edge, but which must have considerable toughness and resistance to shock, should be tempered at a higher temperature. A screw driver requires toughness but not a hard cutting edge, and consequently it may be tempered at 600 degrees Fahr.

Reduction of Strength

The higher the tempering temperature the greater will be the reduction of the tensile strength and the elastic limit. This is not as important in the case of tool steels as it is in the case of the medium carbon steels which are used for parts requiring great strength. Fig. 9 shows that bars which were tempered at the higher temperatures bent further under the same test. The screw driver is an example of a class of tools which should not bend easily. Consequently a temperature of 600 degrees Fahr. is recommended, because this will leave the screw driver quite stiff. A

higher temperature would produce greater toughness but would allow the tool to bend too easily.

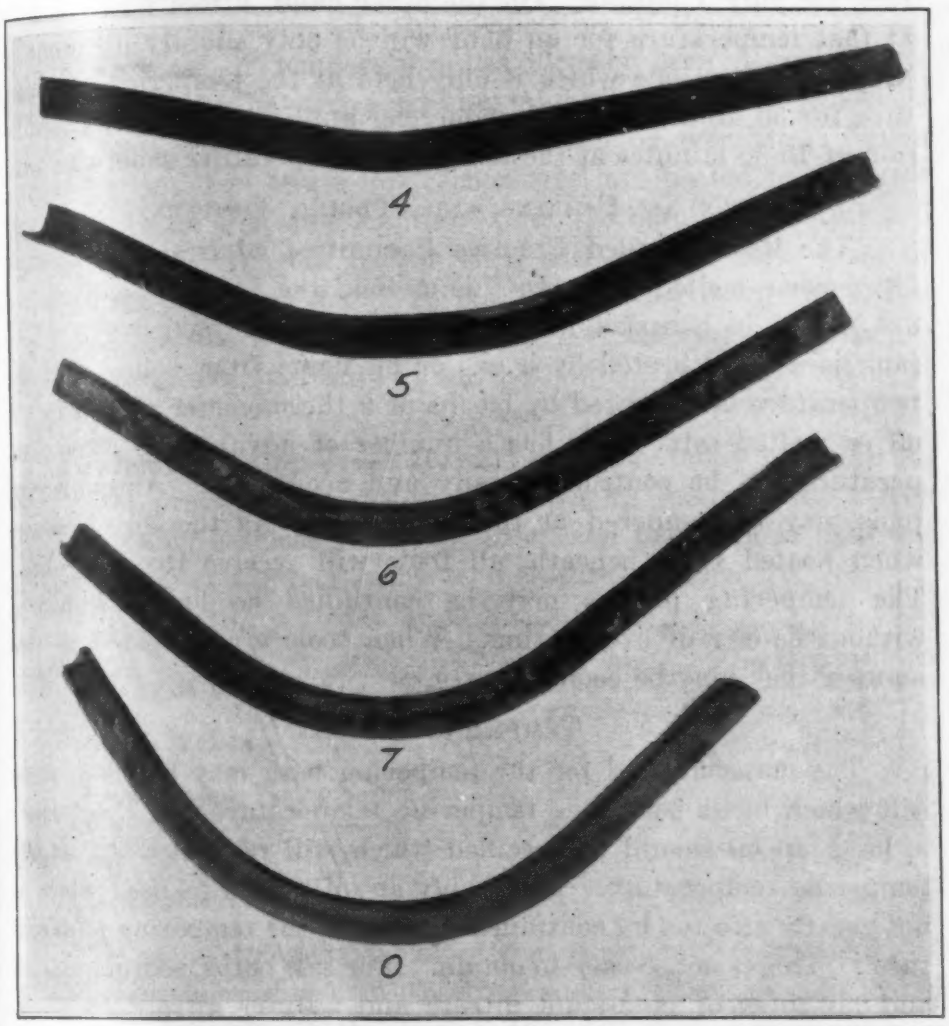

Fig. 9—Photograph of Test Specimens of the Same Bar of Tool Steel After Different Heat Treatments and After Being Given the Same Shock Test. All Specimens were Heated to 1400 Degrees Fahr. Specimen No. 0 was Cooled in Air and Not Tempered. Specimen No. 4 was Quenched in Water and Tempered at 550 Degrees Fahr. Specimen No. 5 was Quenched in Water and Tempered at 750 Degrees Fahr. Specimen No. 6 was Quenched in Water and Tempered at 950 Degrees Fahr. Specimen No. 7 was Quenched in Water and Tempered at 1050 Degrees Fahr.

Time of Tempering

The length of time that the steel is held at the tempering temperature has an effect on the amount of tempering action produced. The action of tempering progresses slowly. However, from the practical view point there is a limit to the amount of tempering which can be produced at any given temperature. A

tool which is held at 450 degrees Fahr. for 20 minutes will show more effects of tempering than one which is held at that temperature for only 1 minute. On the other hand, a tool which is held at that temperature for an hour will be only slightly different in properties from one which is only held at the tempering temperature for 30 minutes. For commercial application, a recommendation of 15-30 minutes at the tempering temperature should be safe.

Method of Heating and Judging Temperature

The Recommended Practice Committee advises tempering in oil or some melted salt. In this method the tools to be hardened are placed in a basket in a tank of hot oil or melted salt. The tank is usually heated by a gas or oil flame from below, and the temperature is measured by means of a thermometer placed in the oil or melted salt. This has a number of advantages. The temperature can be controlled easily and accurately. A number of tools may be tempered at the same time. As the oil circulates when heated from beneath, all tools will receive the same heat. The tempering process may be continued as long as desired without danger of overheating. When tools are tempered in this manner they may be cooled slowly.

Tempering Media

The material used for the tempering bath may be oil or some salt which melts below the tempering temperature. If the former is used, an oil should be specified which will not catch fire at the tempering temperature. Preferably an oil should be used which is not greatly affected by continued heating at the tempering temperature. This is not so easy to obtain. For salt baths, sodium nitrate and mixtures of potassium nitrate and sodium nitrate are used. There are also some commercial salt mixtures on the market for tempering.

Tempering By Color

One of the oldest methods of tempering consists in polishing the steel until it presents a bright surface, and then heating it in air, judging the temperature by the color which appears on the polished surface of the steel. As the steel is heated in this manner it first becomes light yellow. As the temperature rises the yellow deepens into a brown, the brown gradually changes to purple, the purple to blue, the blue to a light blue or blue green and gradually the colors disappear.

This is not a very accurate method of tempering. The colors are due to the action of the air on the surface of the hot steel. The color attained depends upon three factors: (1) the temperature; (2) the time; (3) the composition of the steel. The effect of increase of temperature has already been described. A short exposure at 500 degrees Fahr. might produce a brown color while a long exposure might produce purple or even blue. When a high carbon steel and a low carbon steel are heated to the same temperature for the same length of time, the high carbon steel will be purple when the low carbon steel will only be dark straw or brown. On the other hand, certain alloys slow down the action of the air on the hot steel. Some alloy steels may only reach a straw color at a temperature at which a plain carbon steel would be blue.

Sauveur (quoting from Howe) gives the following table for the colors produced by different tempering temperatures. This table probably assumes that a plain carbon tool steel is used and that the time at the tempering temperature is short.

COLOR	TEMPERATURE	
	Degrees Cent.	Degrees Fahr.
Pale Yellow	220	428
Straw	230	446
Golden Yellow	243	469
Brown	255	491
Brown dappled with purple	265	509
Purple	277	531
Bright Blue	288	550
Pale Blue	297	567
Dark Blue	316	600

The use of the temper colors is still common (particularly in small scale tempering) in treating such articles as cold chisels and screw drivers. In this process the edge of the tool is quenched until cold, and then is quickly polished off. The heat of the shank gradually conducts down to the edge and produces the tempering action. When the desired color is reached the edge is again quenched. Other tools which are tempered to color are sometimes heated on a hot plate or on a hot block or brick. They are quenched as soon as the desired color is reached. The advantages claimed for the color tempering are that the method is cheap, quick, and that it is possible to temper one part of the tool more or less than the rest. The disadvantages are that it leaves too much to the judgment of the hardener; it is easy to make mistakes; colors are not sure

measures of temperature; and the time of tempering is usually not long enough to produce the maximum effects of tempering.

Cooling From Tempering

The rate of cooling from the tempering temperature probably does not make a very great difference in the properties of the steel. The writer prefers slow cooling in the case of plain carbon steel tools whenever possible. Quenching from the ordinary tempering temperature may not produce any appreciable amount of strains, but certainly slow cooling may be recommended as perfectly safe in this respect.

Effect of Tempering Upon the Structure

It has already been stated that hardened tool steel is in the martensitic or troostitic state because the rapid cooling of quenching prevented the austenite from going through all of the steps of the change back to pearlite or annealed steel. It has also been stated that changes in the structure do not readily take place while the steel is cold but do occur when it is hot. Furthermore that the higher the temperature of the steel, the more readily these changes can take place.

It would be natural to expect, therefore, that when a hardened steel is heated for tempering, its structure would tend to continue the change toward the softer condition. Also the higher the tempering temperature the further the change progresses toward the pearlitic structure or annealed steel. This has been found to be the case. It would also seem that the longer the steel was held at the tempering temperature, the further the change would progress. While this is true within certain limits, it has been found that there is a maximum amount of change of structure which can be produced by any certain tempering temperature. For example, several hours at 500 degrees Fahr. does not produce much if any more change in structure than 30 minutes at the same temperature. This is in accord with what has already been stated concerning the change in the physical properties during tempering.

It should be stated that while troostite and sorbite may be produced either by (1) very rapid cooling followed by tempering, or (2) by a little slower cooling without tempering, the structures which are produced by rapid cooling and tempering are much the finer. This probably accounts for the greater toughness of pieces

which are treated in this way. (This will be discussed in more detail a little later.)

The structural changes taking place during tempering are very well represented in a diagram given by Sauveur (Fig. 10). This diagram shows the effect of tempering upon steels which have different structures before tempering. It will be noted that the final structure depends upon the tempering temperature rather than the original structure of the steel. For example, if the steel is tempered at 1112 degrees Fahr. (600 degrees Cent.) it becomes sorbitic regardless of its original structure.

Tests Showing the Effects of Different Speeds of Cooling and Different Tempering Temperatures Upon the Properties of Plain Carbon Tool Steel

In order to show the effect of the different speeds of cooling and the different tempering temperatures upon the properties of plain carbon tool steel, a series of tests were run as described below. For these tests a ¼ x ½-inch bar of "Special", 1.20 per cent carbon tool steel was selected. (This steel really contains a slight amount of alloys but is usually listed as a plain carbon steel. The results produced are substantially the same as would be produced with a steel which contains no alloy). Eight pieces 5 inches long were cut from the same bar and were given the following heat treatments:—

Table I

Bar	Heat Treatment		Hardness		Shock Test						
	Heated to 1400° F. Quenched in	Tempered °F.	Scleroscope Reading	Brinell Number	Bend after dropping hammer from heights stated						
					6"	9"	12"	18"	24"	30"	36"
0	Air	None	37	229	¼	5/8	1 1/8	1¼	1½	...	...
1	Oil	None	70	415	⅛	¼	7/16	¾	1	Broke	...
2	Water	None	95	653	Broke	..	..	..	...	...	...
3	Water	450	95	653	..	1/32	1/16	Broke	...	...	...
4	Water	550	85	601	..	..	1/32	⅛	¼	5/16	7/16
5	Water	750	70	555	1/32	1/16	3/32	5/16	½	5/8	7/8
6	Water	950	65	363	1/16	3/32	3/8	9/16	¾	1 1/8	1 1/8
7	Water	1050	55	341	3/32	¼	½	¾	1	1⅛	1⅜

Bar No.	Method of Cooling	Tempering Temperature Degrees Fahr.
0	Cooled in air	Not tempered
1	Quenched in oil	Not tempered
2	Quenched in water	Not tempered
3	Quenched in water	450
4	Quenched in water	550
5	Quenched in water	750
6	Quenched in water	950
7	Quenched in water	1050

All pieces heated through at 1400 degrees Fahr., and then cooled and tempered as stated.

After receiving these heat treatments, each bar was tested for hardness with the scleroscope and the Brinell and was given a crude shock test. In performing the shock test, the bar was laid flat accross the top of a special V-block so that the ends of the bar

Fig. 10—Diagram Showing the Tempering of Hardened Steel. (Sauveur.)

were supported by the block. A 35-pound hammer with a round peen was raised and dropped through vertical guides, striking the center of the specimen. The hammer was thus dropped from heights of 6, 9, 12, 18, 24, 30 and 36 inches above the specimen. After each blow the bar was removed and the total amount of the bend or deflection was measured. The results are recorded in the data of Table I given herewith. Whenever a specimen broke the word "broke" appears in the proper column, showing which blow of the hammer caused the failure.

Fig. 9 shows a photograph of the bars which went through the entire test without breaking. It will be noted that the higher the tempering temperature the greater was the amount of the bend produced by the same amount of shock. On the other hand, the ones which received low tempering treatments or none at all while not easily bent, were much more easily broken.

Especial attention is called to the difference in the results produced on bars 2 and 3. Bar 2 was quenched in water and not tempered, while bar 3 was quenched in water and tempered at 450 degrees Fahr. Both showed the same hardness (653 Brinell

and 95 scleroscope) and yet there was a vast difference in their ability to withstand shock. The bar which was not tempered, broke under the first blow of the hammer (6-inch drop), while the bar which was tempered 450 degrees Fahr. withstood the 6, 9, and 12-inch blows and was finally broken by the 18-inch drop of the hammer. This should show the great difference in the shock resistance which may be accomplished by a low tempering temperature which does not measurably reduce the hardness. The bar which was tempered at 450 degrees Fahr., withstood several times the shock of the one which was not tempered. It may be well to state that if the hardness had been determined by measuring the the cutting efficiency of a hardened tool it might be noted that even a tempering temperature of 450 degrees Fahr. might show some softening action. However, a tempering temperature of 375 degrees Fahr. will show little or no decrease of cutting efficiency and will produce much greater toughness and resistance to shock than can be produced by quenching and not tempering.

The results on bars 1 and 4 show the great difference between the properties produced by oil quenching and not tempering, and water quenching and tempering far enough to produce the same hardness. Bar 1 was quenched in oil and not tempered. Bar 4 was quenched in water and tempered at 750 degrees Fahr. Both showed about the same scleroscope hardness and bar 4 (water quenched and tempered) showed even a little greater Brinell hardness. Nevertheless the bar which was quenched and tempered showed greater resistance to shock. It went through the entire test without breaking, while the bar which was quenched in oil and not tempered broke under the 30-inch blow.

It should be stated that these results are not unusual. These tests are performed by each class under the writer's instruction, and while there are some variations in the results, the general principles illustrated are always the same. The oil quenched and untempered piece always breaks easier than the piece which is water quenched and tempered to produce the same hardness. In a similar test the piece which was quenched and tempered at 750 degrees Fahr. not only went through the entire shock test but was afterwards bent in a vise to an angle of 60 degrees before it broke. The bars which were tempered higher bent even further before breaking.

Some hardeners seem to think that the hardness tests are a safe guide for judging the other properties of steel. These tests should show that such is not the case. The toughness and resistance to shock depends more upon the way the hardness is produced than on the actual hardness itself. The careless way of speaking of articles which are not tough enough as being "too hard" should be discouraged. Hardness and brittleness are not the same thing; neither are softness and toughness the same property. It should not be concluded from the foregoing that oil quenching has no place in good heat treating. It is sometimes very advantageous. The cooling being less rapid, there is less danger of cracking during quenching.

Summary

The microscope shows that there is a difference in the structure of a tool steel depending upon the heat treatment. An 0.85 per cent carbon steel in the annealed condition is pearlitic. When heated above the Ac point, it becomes austenitic or a solid solution. The formation of austenite requires time. On slow cooling the austenite passes through several stages in the change back to pearlite. These are called martensite, troostite and sorbite. Fast cooling prevents the steel from changing completely to pearlite and leaves it in one of the intermediate stages. Martensite is the hardest structure. Troostite and sorbite are less hard but tougher. In commercial practice a mixture of structure is frequently produced.

For hardening, steel should be heated to an exact temperature. This temperature should be measured by a pyrometer. The steel should be heated slowly and uniformly.

Steel is hardened by quenching in a proper medium. The faster the quench the greater is the hardness produced. Different quenching media produce different speeds of cooling. Circulation of the quenching medium increases the speed of cooling. Steel should be quenched so as to produce as uniform cooling as possible. It is best to remove the tool from the quenching tank while still warm and temper immediately.

Tempering or drawing is reheating after hardening to some temperature below the Ac point. It relieves strains, toughens, and reduces the hardness and the strength. The higher the tempering temperature, the greater is the effect. The tempering action is usually nearly complete at the end of 30 minutes. Tempering by

color is open to errors. Tempering in a liquid bath is recommended.

Tempering changes structure from martensite to troostite to sorbite, depending upon the tempering temperature.

The tests described bear out the statements made concerning effects of quenching and tempering plain carbon tool steel. They show that a low tempering temperature greatly increases toughness and resistance to shock with very little reduction of hardness. They show that the hardness of a steel is not a measure of its toughness or resistance to shock. The water quenched and tempered specimens are tougher than the ones of the same hardness which were oil quenched and not tempered.

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CARBURIZING AND HEAT TREATMENT OF CARBURIZED OBJECTS

By B. F. Shepherd

Abstract

Recommendations for carburization and heat treatment of carburized parts are given in this paper. The data presented represents the average practice in several up-to-date manufacturing plants.

The author has discussed the advantages of carburizing steel parts, the factors governing the process, and the selection of the proper steel. He discusses the action of carburizing compounds, the properties of carburizing compounds and methods of testing to determine the suitability of a given compound.

The subject of carburizing boxes or containers is discussed from the viewpoint of design and composition.

Heating practice, both for carburizing and hardening, and determination of the depth of the carburized zone are covered.

Introduction

THE recommendations given herewith are intended only for guidance and are not to be construed in any manner as being specifications of the A. S. S. T. Any recommendations for carburizing and the heat treatment of carburized objects must, necessarily, be very general in scope, due to the wide range of application for case hardened objects and the influence upon the process of works practice and operating conditions. The data given herewith is representative of the average practice in a number of manufacturing plants having good works practice. Some essential features of the process may be briefly reviewed.

Description of Process

The carburizing process depends upon the absorption of carbon (and other hardening elements) by the steel at temperatures under the melting point and above the lower critical temperature. High temperatures result in an extremely undesirable structural condition, i. e., coarse grain, excessive concentration and unfavorable distribution of excess carbon, sharp junction of case and

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core, warping and distortion of parts, high cost of materials (furnace linings, packing pots, etc.). The service life of these latter materials decreases rapidly with an increase of working temperature. Low temperatures result in a slow penetration of the carbon. Intermediate temperatures are, therefore, chosen for the operation.

Advantages

The use of partial cementation, or carburizing, as a method of heat treatment has increased, owing to the difficult service requirements to be met by modern machinery. The process creates a duplex steel capable of being made extremely hard and wear resistant on the outside and having a strong, tough inner portion or core. This type of structure is suitable for parts which are required to stand considerable shock and friction. Parts which are required to be hardened on small portions of the total mass may be rough machined, carburized, and the case removed by machining from the section which it is desired to keep soft. The added advantage of machining a softer and cheaper material also lessens the cost of the part. Engineers often overlook the problems encountered in the heat treating department and design parts of complicated form which are to be hard on the surface. If these parts are made from a high carbon tool steel, the hardening operation would have a tendency to crack them and the use of a carburizing operation on low carbon steel makes the hardening operation less hazardous.

Factors Governing Process

The primary factors which govern the properties of case hardened parts are:

1. Chemical composition of the steel.
2. The carburizing operation.
3. The hardening operation.

Steel

Carburizing steels should be selected according to the service requirements of the parts to be made from them. It must be remembered that the carburizing process cannot remove imperfections, irregularities or faults in the steel. It will magnify them.

Parts should not be made from a carburizing steel if it is possible to obtain satisfactory results from another type of steel, heat treated. The equipment needed for the carburizing operation, the materials used, the time consumed, and the supervision required cause a heavy labor and overhead charge which increases the cost of the finished part.

Selection of Steel

The heat treatment which the part is to receive and the machinability of the steel should be considered. Several well known types of steel may be adopted as standard. It is preferable to have these conform to specifications of national engineering societies. For special cases it may be necessary to have special analyses, but adherence to a few steels will result in better service from the steel manufacturer when business is good and steel is difficult to obtain. Less steel will be required for stock purposes as the sizes for the various parts will duplicate and a smaller quantity in stock will meet all demands. A better knowledge of methods of handling in the heat treating department will result as familiarity with certain well known types increases.

Sources of Supply

Each type of steel should be procured from several manufacturers and experience will show the quality which each can furnish. They should be graded and purchases made accordingly. The steel should be carefully inspected when received, for chemical analysis, surface, size, seams and occasionally fracture and microstructure.

Carbon Steel

A well made carbon steel will be satisfactory for most ordinary purposes and a variation in analysis between the S. A. E. limits will not materially influence the results. The machinability can be increased by raising the carbon content to a maximum of 0.30 per cent. This element, in both simple and alloy steels, should preferably be below 0.20 per cent. A high manganese content, i. e., above 0.60 per cent, is generally supposed to induce a brittle core. High manganese, however, is sometimes specified to obtain increased surface hardness and increased core strength. These types

are hardened in oil. High phosphorus and sulphur contents increase the machinability but generally indicate a steel of poor quality. These elements are, however, many times added intentionally to steels of good quality to increase the machinability. A low silicon content, i. e., below 0.10 per cent, sometimes indicates a steel which has been poorly deoxidized in the process of manufacture, especially those steels in which other deoxidizing agents have not been used.

Alloy Steel

The alloying elements which are generally added to carburizing steels to increase the strength and wearing qualities are chromium, nickel, vanadium and molybdenum, either alone or in combination. Nickel tends to retard the grain growth at carburizing temperatures, and produces a strong and tough core, the percentages usually used being 0.5 to 5.0 per cent. Chromium is used alone in percentages up to 1.25 per cent and gives a greater abrasive hardness to the case. S. A. E. steel 3115, containing about 1.25 per cent nickel and 0.60 per cent chromium is recommended for general high grade use. Molybdenum, about 0.15 to 0.25 per cent, or combined with about 1.5 to 2.0 per cent of nickel is used with good results. The use of molybdenum steel containing chromium is not recommended, as this steel has an inherent tendency to distort in the carburizing operation.

Carburizing Process

Divisions

The carburizing materials are divided into three classes, solids, liquids and gases, the solid type being generally used. In this process, the parts are placed in suitable pots or containers, surrounded by the carburizing material and the pot closed by a lid. The carbon is absorbed from gases generated by the compound. The lid should seal the pot thoroughly to prevent the escape of these gases. The liquid baths are cyanogen compounds and the parts are immersed in the liquid. Most of the salts used are very poisonous, although there is one bath in commercial use which is not. In gas carburizing, the parts are placed in a heated container, which is then sealed and a gas of definite composition passed through it.

Action of Compound

All carburizing compounds depend on carbonaceous gases as a carrier of the carbon into the steel. The amount and nature of these gases, and the rate at which they are generated by the compound, determines to a great extent the carbon penetration into the steel and the carbon content of the case. A well balanced composition of the compound is, therefore, necessary in order to obtain desired desults in the carburizing operation. The physical properties must, in addition, be such as to allow handling in commercial practice.

Properties of Compound

Almost every kind of carbonaceous material has been used, the usual ingredients being at present charcoal, charred bone, charred leather, bituminous coal, and different kinds of coke. The latter is added as a filler and to reduce shrinkage. The efficiency of a compound is determined by:

1. The rapidity with which it transmits carbon to steel at the various temperatures of carburization.
2. The ability of the compound to be used over and over again without loss of carburizing power.
3. Low specific gravity, as compounds are purchased by weight and used by volume.
4. The ability to maintain the same volume when packed.
5. Low shrinkage loss per run. It is much better to have a compound shrink gradually than to have a high initial shrinkage.
6. Freedom from pitting the steel or imparting to it undesirable constituents.
7. Freedom from dust.
8. Relatively good thermal conductivity.

Defects of Compounds

The compound which does not carburize uniformly produces a case of irregular carbon content. Soft spots are then found after hardening, due to the carbon content of the soft spots not being high enough to harden satisfactorily. These spots may be caused by an actual non-uniformity of the compound or by the

caking of some of the fine powdered portions against the surface of the part, which would prevent the carburizing gas from coming in contact with the steel. In general, the velocity of penetration is greater if the gas generated can circulate freely around the compound and the steel with which it must react alternately.

Tests of Compound

Most of the compounds used today are manufactured according to more or less secret formulas and it is well to standardize on certain brands from a reliable manufacturer. Each shipment

Table I

Recommended Temperatures and Cooling Mediums to be used for Carburizing and Heat Treatment of Carburized Objects.

	PRELIMINARY HEAT TREATMENTS use either A or B.						CARBURIZING		REFINING AND HARDENING TREATMENTS				
	A		B										
Steel No.	Normalizing Temperature	Cool in	Quenching Temperature	Cool in	Reheat to	Cool in	Temperature	Cool in	Regenerative Quench	Cool in	Hardening Quench	Cool in	Tempering Temp.
S. A. E.													
1020	1650	air	1650	oil	1100	air	1650	pots	1600	oil	1425	brine	400
1015	1650	air	1650	or	1100	air	1650	pots	1600	oil	1425	brine	400
1025	1650	air	1650	water	1100	air	1650	pots	1600	oil	1425	brine	400
2320	1700	air	1525	oil	1000	air	1650	pots	1525	oil	1375	oil	325
2315	....	..	....	....	....	..	....	...	....	..	....	....	...
2512	1650	air	1525	oil	1100	air	1625	pots	1525	oil	1375	oil	325
3115	1700	air	1600	oil	1000	air	1650	pots	1550	oil	1400	oil	325
3120	1700	air	1600	water	1100	air	1650	pots	1550	oil	1400	water	325
....	....	..	....	....	....	..	....	...	....	..	1440	oil	325
3215	1700	air	1550	oil	1150	air	1650	pots	1550	oil	1425	oil	325
3220	1700	air	1550	oil	1150	air	1650	pots	1550	oil	1400	oil	350
3312	1650	air	1525	oil	1200	air	1625	pots	1575	oil	1400	oil	375
3325	....	..	1500	oil	1200	fce.	1625	pots	1575	oil	1400	oil	375
3415	1650	air	1550	oil	1150	air	1625	pots	1550	oil	1400	oil	350
6120	1650	air	1650	oil	1100	air	1650	pots	1625	oil	1475	brine	375

Note: The temperatures and cooling mediums given in this table are dependent upon and must be varied according to the instructions given in the main section of the recommended practice. Particular attention should be given to varying the regenerative temperature with the size of the part and degree of distortion which must be avoided.

of incoming material should be tested by packing a few pots with the new compound and carburizing with them at a fixed temperature for a fixed time. An examination of the test specimens will give standards which can be used to compare new lots of material.

Charcoal Compounds

Charcoal alone is not sufficiently active to sustain carburizing for any appreciable length of time. The common types of compounds have a hardwood charcoal base, with the addition of coke

as a filler to reduce shrinkage, and chemicals to energize the action. Some large users specify the composition and properties of their carburizing material, the specifications usually varying between the following limits:

	Per Cent	
Hardwood charcoal	40–65	
Barium carbonate	5–16	
Calcium carbonate	2– 7	
Sodium carbonate	3–12	
Moisture	3– 5	
Shrinkage, first run	20–25	max.
Weight per cubic foot	20–34	pounds

It has recently been shown that 2½ to 5 per cent of barium carbonate alone, has as great an influence upon wood charcoal as larger quantities.[1]

Bone Compounds

A distinctly different class of compounds are those with charred bone as a base. Their compositions are usually as follows:

	Per Cent	
Charred bone	70 –80	
Hardwood charcoal	10 –15	
Oil	10 –15	
Energizing chemicals	none– 3	
Weight per cubic foot	45 –60	pounds
Skrinkage after first run	–	negligible.

This compound is slow in action, but will sustain carburizing practically indefinitely. The weight per cubic foot is high and the compound is, therefore, expensive to use. The heat conductivity is low and a longer time must be allowed for bringing pots packed with bone base compound to carburizing temperature than when a charcoal base compound is used. The shrinkage, when used in commercial proportions, i. e., one part new to 3 or 4 parts old compound, is negligible, which is of great importance when long heating periods are required. These compounds heat faster after being used for the first time.

Shop Mixtures

The shop mixture of a compound consists of mixtures of new and used compound varying between 1 to 1 and 1 to 5 with the usual proportions, 1 part new to 3 parts used material. Energizing compounds of the charcoal base type should be given oppor-

[1] TRANSACTIONS of the American Society for Steel Treating, Vol. VI, November, 1924, pages 606 to 614.

tunity to take up carbon dioxide from the air in order to restore the carbonates which have been reduced to oxides in the carburizing process. The used compound should be screened in order to remove the dust. A good machine for this operation has recently been placed on the market. The compound may be mixed by hand or mechanically, depending upon the quantity of the material used.

Materials

Container Materials

Packing pots are made from cast iron, cast and pressed steel and special heat resisting alloys. Cast iron and steel containers are of short life and are subject to warping and scaling. Cast iron usually lasts 200 to 300 hours and cast and pressed steel 700 to 1000 hours. The warping of the pot has a tendency to introduce scale and foreign material into the carburizing material, which may cause soft spots on future work.

Basis of Comparison of Containers

Comparisons of containers are usually made on a heat hour cost basis, the length of life of the containers being determined by actual service and this figure divided into the cost of the pot, which gives the cost per service heat hour. The more expensive special heat resisting alloys have a longer life and their cost per heat hour is in most cases below that of the cheaper containers.

Alloy Containers

The special heat resisting alloys usually have a service life of 3000 to 5000 heat hours, depending upon local operating conditions. They are much less subject to warping. There are a number of satisfactory alloys on the market, the chromium-nickel alloys with a small percentage of iron being usually found to give the best service. When trouble is encountered with these materials, it is usually due to cracking and casting defects.

Container Design

The design of the pot is of primary importance as well as the proper distribution of metal in the walls, reinforcement ribs,

legs, etc. A compromise in size is found between the very small containers, which are expensive in handling practice and the large containers which have a tendency to heat unevenly. A longer life can be expected from round pots with or without a chimney in the center than from pots of square or rectangular design. The size of the pot should be governed by the size of the parts. Small parts should not be placed in an extremely large pot, as there is a considerable temperature gradient between the outside and the center while passing from the critical temperature where carburizing starts to the carburizing temperature where the shop man starts to count "hours after heated through."

Heating Practice

Factors Influencing Heating of Pots

The effective temperature or the temperature inside the pot and the carburizing time is usually spoken of as so many hours after heated through at the carburizing temperature. The heating

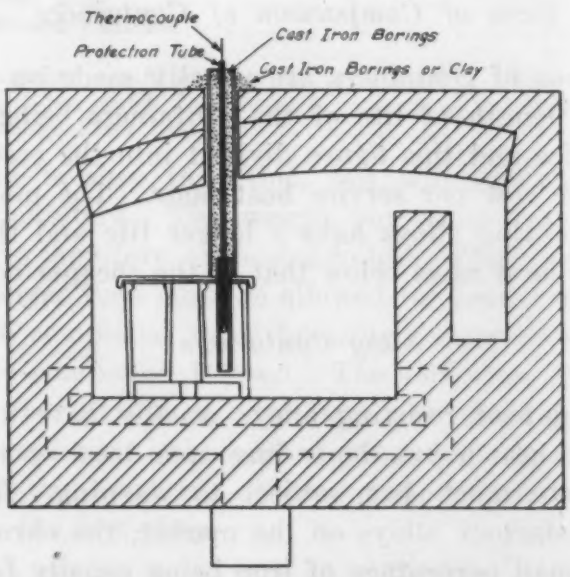


Fig. 1—Diagram Showing Arrangement of Thermocouple in Carburizing Box.

through of the pots is judged in two ways; by estimating with the eye, and by thermocouples placed inside the pot (see Fig. 1). The first method must be used on pots which are so small that it would be impracticable to place a thermocouple inside them. A number of factors will have an influence upon the time of heating

to temperature and should be considered. A hot furnace will bring a capacity load of pots to temperature much quicker than a cold furnace. One pot will be brought to temperature much quicker from either of these furnaces than a capacity load. The time of heating to temperature should be standardized for each size of pots and this schedule time adhered to by the furnace operator who has direct control of the local conditions. The recording of the temperature by a thermocouple inside the pot makes a schedule heating much easier for the operator. A thermocouple should also be placed in the furnace so that the furnace temperature may be more readily controlled, as otherwise excessive furnace temperatures or extremely variable heats will be obtained.

The time of heating to temperature is also dependent upon the degree of distortion which it is desired to avoid. Quick heating always has a tendency to produce more distortion than a slower heating, and this factor must be borne in mind. The temperature in any pot must be comparable with the temperature inside any other. To this end the furnace must be designed to heat evenly and the pots must be spaced on the furnace hearth so that they will heat evenly and uniformly. They should also be lifted off the furnace floor by short, stubby legs, so as to allow a free circulation of the heating gases. The containers in different parts of the furnace should reach the carburizing temperature simultaneously. The outside and corners of the containers heat more rapidly than the interior and some pots, usually in front of the furnace, near the door, will be heated slower than the others. A certain amount of variation is unavoidable even in the same furnace, but with standardized furnace practice, this variation should not exceed 20 per cent in case depth.

Heat Treatment

Carburized Zone

The carbon content at the surface of the work increases with the carburizing temperature. The formation of free carbide at the grain boundaries is undesirable, as it leaves a very brittle surface exposed to service stresses. Good carburizing practice requires that this carbon content be kept to about 1.15 per cent, with an even gradation of the carbon content toward the core.

The amount removed by grinding will reduce the carbon in the exterior layer to about eutectoid proportions. The carbon content is determined by the carburizing temperature and the compound, while the gradation depends upon the analysis of the steel and rate of cooling of the pots. The allowable temperature to a great extent depends upon the nature of the work. Where speed and expense are primary considerations, temperatures of 1725 to 1750 degrees Fahr. (940-955 degrees Cent.) may be used. For general practice, 1650 degrees Fahr. (898 degrees Cent.) will give a satisfactory rate of penetration. When the regenerative quench is not to be used, it is good practice to carburize about 100 degrees Fahr. lower than usual, in order to preserve, as far as possible, a fine grain in the core, together with all the toughness that can be secured. Thin cases, of 10 to 15 thousandths, are better obtained with a low carburizing temperature of 1500 to 1550 degrees Fahr. (815-843 degrees Cent.), as this can be controlled to produce more uniform heating. Before unpacking the containers, it is good practice to check the depth of case by quenching a sample piece in water and comparing the fracture with the desired depth.

Measurement of the Carburized Zone

The term "depth of case," as used in the shop, is the depth of the refined case to be observed with the naked eye after carburizing, hardening and breaking for fracture. This depth is the term referred to, unless otherwise specified. On many steels it is hard to judge with extreme accuracy, particularly on those steels which harden in oil and which have strong cores.

Regenerative Quench

After carburizing for the desired time the grain size of the case and core will have increased due to the long soaking at high temperature. If allowed to cool in the pots, the excess case will form a network between the grains, or separate in large masses, depending upon the type of steel used. This slow cooling also tends to produce an extremely coarse grained core. After heating and quenching from a temperature which will give the best case refinement, the carbide structure will not be changed and will form an easy path for fracture due to its intrinsic brittleness. The structure of the core will also remain unaffected. Quenching from the carburizing temperature where this excess carbide is in solution will not allow it to form a net work or to precipitate in large masses.

The core will also be much finer grained and considerably harder, unless the carbide content is very low. The disadvantages are: with the high carburizing temperature and long exposure the case and core are both incompletely refined; the proper quenching temperature for the core is about the same as or below the usual carburizing temperature; large work is difficult to handle on account of the heat. The best core condition can be obtained by allowing to cool in the pot, reheating and quenching from a temperature which will refine the core and also break up any undesirable structures of cementite. This quench is called a regenerative quench because it regenerates or restores the structure of the case and core. It is generally made from a definitely fixed temperature. If no excessive carbide is formed, the regenerative treatment is only necessary for the refinement of the core. If the carburizing temperature is comparatively low and the time of exposure short, the grain will not grow excessively, especially with certain steels, and a quench from the carburizing temperature will produce the necessary regenerative effect.

Cooling of Pots

The cooling of carburized parts is usually allowed to take place in the containers, outside the furnace. In this way, the exfoliation of the case from the core after hardening is suppressed and the detrimental effect of any excess carbon in the outside layers of the case is greatly reduced.

Depth of Case

For most case hardened parts a hard surface, able to resist wear, is the primary consideration, and an even hardness without soft spots is, therefore, required. For many applications, the nature of the service also requires a strong, tough core in order to impart proper strength. The case resists wear and strengthens the part. A case which is too deep not only costs more to produce but surrounds the core with a hard, brittle, unyielding exterior, and any heat treatment which is given the core in an endeavor to toughen and refine it is of little avail. When such a piece receives a severe shock, the fracture of the case will occur suddenly and the toughness of the core will have little influence in resisting total failure of the part.

In carburizing, sufficient allowance must be made for the metal which will later be removed by grinding. This will amount

to 10 to 15 thousandths for most parts, excepting those which warp badly and require a more generous allowance. A sufficient depth of case is required to allow the piece to harden uniformly without the liability of soft spots and to a depth so that the piece can stand a certain amount of wear and still present as hard a surface to the wearing action as it presented in the beginning. The wear on many parts is limited as the loss in efficiency of the part is so great after a certain period of time that it is much better to throw the part away than to continue to use it. A deep case will not prevent the part from being discarded after it becomes excessively worn so that the loss in mechanical efficiency is a greater factor in the service life than the preservation of a hard wearing surface.

Hardening Temperature

The hardening temperature of the case is below the critical temperature of the core and the grain size produced in the core by the carburizing temperature or regenerative quench is not affected. The hardening temperature is usually chosen as the temperature which gives the best fracture on several dummies or experimental pieces hardened from various temperatures. The figure given in Table I is the middle of the range of probable hardening temperatures.

Hardening Hazards

An intricately shaped part will probably be made from a carburizing steel, owing to the hazards which would be encountered in hardening, if made from tool steel. It should, therefore, be hardened carefully, i. e., preheated, heated thoroughly and uniformly, and cooled at the slowest rate which will give the desired hardness. The practice of quenching from the carburizing pot without a subsequent rehardening leaves the case in a very coarse and undesirable condition, and should never be used, except where cheapness of treatment is the only consideration.

Distortion

Distortion must be avoided in many parts. This can be done, not by care in one operation, but by extreme care from the beginning. The steel must be selected and inspected carefully. The parts must receive a preliminary heat treatment after or before the rough machining operation. The method of carburizing must be studied and the subsequent hardening operations carried on with extreme care as to the heating and cooling cycles. In many cases,

the regenerative quench must be omitted, because the high temperature of this operation causes too much warping. When the regenerative quench is omitted, it is common practice to carburize at 100 degrees Fahr. lower temperature to avoid distortion. The only recommendations that can be given in a table are the preliminary heat treatments.

Tempering

Severe service conditions demand the best structural condition in the part. This can undoubtedly be obtained by allowing to cool in the pot, giving a regenerative quench, hardening quench, and tempering operation. Tempering may be carried on for the relief of strains at a low temperature or at higher temperatures for the increase of toughness and uniformity without materially reducing the hardness. An oil bath is preferable to an open furnace for temperatures up to 600 degrees Fahr. (315 degrees Cent.). For simple carbon steels, a softening of the surface is obtained after the tempering temperature exceeds 375 to 400 degrees Fahr. (190-205 degrees Cent.) and for maximum hardness the tempering temperature should be kept below this. Most case hardening work is finished by grinding and the tempering operation will materially reduce the tendency for the formation of grinding cracks. It will also diminsh the tendency to distortion after finish grinding, i. e., aging.

Furnace Practice for Hardening

It is also necessary to observe proper precautions in regard to furnace practice in the heat treating operations. Salt bath furnaces avoid scaling and overheating. They are expensive in maintenance and operation. Constant vigilance is necessary to keep the composition of the bath so that it will not decarburize the work. Lead baths offer the advantages of salt baths and are very useful. Small hearth-type furnaces require care to ensure that the pyrometer reading not only indicates the temperature of the tip of the thermocouple but the temperature of the furnace and work. Continuous furnaces with movable hearths are applicable where a production schedule exists which can keep them going.

Cost Versus Quality

The shape of the piece, class of the steel and service conditions regulate the heat treatment which can be given the part. The

best quality can be produced at a certain cost and any reduction or restriction of this cost which interferes with the heat treatment which can be given the article must result in a product not of the highest possible quality. There are many parts not requiring this quality which must be made at low cost. For these, intermediate treatments must be used, such as quenching directly from the carburizing pots, possibly followed by tempering; quenching directly from the carburizing pots followed by hardening and possibly tempering.

Testing

The best method of testing the carburizing operation is to examine the case after subjecting the part to the standard heat treatment. This examination may be made by breaking the part for fracture, or by taking sections from it and examining them under the microscope. The fracture-test is easily made a routine inspection and gives a check on the quality of the material leaving the heat treating department. The Brinell hardness test is inapplicable, as it punches through thin cases and is affected by the depth of case. Scleroscope tests give comparative values on the same materials but are affected to a great extent by the shape and size of the part. The file test is a shop method of testing hardness. It is quite a satisfactory method.

Fracture

The examination of the fracture should show whether the case is of sufficient depth; if it is well refined; etc. It is well to adopt a definite standard of depth which should be noted on the heat treatment instruction card. The method of breaking for fracture; gradually or quickly, across or with the grain, alters the fracture and apparent depth of the case considerably. Before rejecting the part on account of insufficient depth of case, it should be broken several times.

Use of the Microscope

A microscope is used as a supplementary means of inspection on special work. It is a matter of a few minutes for the metallographist to polish, etch, and examine a specimen for depth of case, distribution of carbon, free cementite, etc. The following table shows in condensed form the most common defects in case hardened work, the possible reasons, and methods for their identification and correction.

Defect	Case	Indication	Correction
Depth of and carbon content outside specified limits.	A. Carburizing temperature not correct.		
	A1. Furnace temperature uneven. Temperature of containers not uniform.	Results vary in the same furnace and from the same containers.	Redesign furnaces. Modify heating practice. Allow longer time for bringing furnaces to temperature.
	A2. Faulty pyrometer readings.	Entire furnace loads unsatisfactory.	Check pyrometer system.
	A3. Carburizing compound too weak or too strong.	Results from entire department vary from usual results.	Check carburizing compound before accepting shipment. Change time and temperature until desired results are obtained.
Soft spots obtained in hardening.	B1. Improper hardening temperature low or uneven.	File test.	Raise hardening temperature.
	B2. Improper quench.	File test.	Use faster quench brine or spray.
	B3. Surface decarburized.	File test. Determine whether decarburization occurred in carburizing or hardening furnace.	Correct carburizing practice. Correct heating practice for hardening.
	B4. Low carbon content or uneven penetration.	As above B-3.	Correct carburizing practice. Try other compound. Check pyrometers.
Unsatisfactory Fractures.	C1. Too high hardening temperatures.	Fracture tests.	Decrease or adjust hardening temperature.
	C2. High surface carbon. (freckled edges)	Fracture tests.	Decrease hardening temperature. Use double quench with rather high temperature for regenerative quench. Use weaker compound.

Acknowledgment is made to Robert Schenck, W. R. Shimer, E. W. Ehn and especially to F. P. Martin, whose extensive experience has been largely drawn upon, and to H. S. Brainerd for his inspiration in the furthering of this work.

Comment and Discussion

Papers and Articles Presented Before the Society and Published in Transactions Are Open to Comment and Criticism in This Column—Members Submitting Discussions Are Requested to give Their Names and Addresses

DISCUSSION OF R. G. GUTHRIE'S PAPER[1] ENTITLED "HIGH POWER MAGNIFICATION IN METALLOGRAPHY"

By H. M. Boylston[2]

I have great admiration for any one who has the patience and skill for making photomicrographs of metal specimens at very high magnifications, and Mr. Guthrie is to be congratulated on his attempt to show the effect of the type of illumination and the influence of the kind of objective chosen for high power work.

There are one or two points to which I should like to call attention as they come to mind on reading through his article. For instance, it is quite apparent from a comparison of his Figs. 2 and 3 that plain axial illumination shows clearer detail than conical illumination without losing anything in contrast. He has presented photomicrographs, however, which run in magnification all the way from 350X (Fig. 7) to 12,500X (Fig. 11), and there are some discrepancies here which I find hard to explain.

For instance, comparing Figs. 4, 5 and 6, evidently taken from the same spot on the specimen, he gives magnifications of 1500X, 2000X and 5000X respectively. Assuming that Fig. 4 marked with a magnification of 1500X is correct, I have carefully measured the distance between certain points on the original prints corresponding to this figure and Figs. 5 and 6 and have calculated magnifications of approximately 2240X and 3270X respectively for Figs. 5 and 6. That is to say, he apparently has underestimated the magnification in the case of Fig. 5 and overestimated it by a considerable amount in the case of Fig. 6. If my calculations are correct and assuming that Fig. 4, marked 1500X, has the magnification marked correctly and that Fig. 6, marked 5000X, is in error, then assuming that the same error is made in determining the magnification of Fig. 11, the actual magnification of Fig. 11 should be approximately 8175X, instead of 12,500X. It is impossible to check this up directly, because it is not clear that Fig. 11 was taken from the same spot as either Fig. 4 or Fig. 6.

To make the matter clear, I have set down my results below in the form of a table in which are given the figure number, the distance in inches between certain corresponding points in Figs. 4, 5 and 6, the magnifications as marked for Figs. 4, 5, 6 and 11, and the correct magnifications as calculated by me, on the assumption that Fig. 4 is marked correctly as to magnification.

[1] Transactions of A. S. S. T., January, 1925, Vol. VII., No. 1, Page 4.

[2] The author of this discussion, H. M. Boylston, member A. S. S. T., is professor of Metallurgy, Case School of Applied Science, Cleveland.

Calculated Magnifications of Figures 5, 6 and 11

Fig. No.	Distance in Inches between Certain Corresponding Points	Magnification as Printed beneath the Photomicrograph	Calculated Magnifications Assuming Fig. 4 to be Correctly Marked
4	2.375	1500X	
5	3.55	2000X	2240X
6	5.17	5000X	3270X
11		12500X	8175X

I would add also that in my opinion Figs. 5, 6 and 11 are excellent examples of empty magnification, since they do not show us anything that cannot readily be seen in Fig. 4, for instance, or, for that matter, in Fig. 2.

AUTHOR'S REPLY

In answer to Professor Boylston's discussion of my paper, I should say that it is our practice to very carefully measure the magnification of all photomicrographs taken after the actual photographing has been completed, using for this purpose a stage micrometer graduated in hundredths of a millimeter. The procedure in the case of the photomicrographs under discussion was to first take all of the photomicrographs, in each case noting the exact conditions under which the photomicrographs were made, and, later, setting up these conditions and using the stage micrometer in place of the sample. The magnifications are all measured as correctly as it is possible to measure them with a millimeter scale.

Taking the points that Professor Boylston brings up in the order of their appearance in his discussion, the first one, in his second paragraph is the one in which he compares Figs. 2 and 3 and makes the comment that Fig. 2, taken with plain axial illumination shows clearer detail than Fig. 3, taken with conical illumination. The point that he brings up was not emphasized particularly in the paper under discussion, but was discussed rather in detail in a later paper read before the sectional meeting at Cincinnati, Ohio, in which this point was made very clear. I would refer the reader to that paper published in TRANSACTIONS, March, 1925. Of course, Professor Boylston may have a preference for flat, axially illuminated photomicrographs, and if he does that is perfectly all right, as everyone enjoys the right to their own tastes in matters of this kind. I will say in defense of the photomicrograph of Fig. 3, and conical illumination in general, that this plate is not a good example of conical illumination; in fact it is not a good example of photomicrography at all and is probably the poorest plate in the entire paper. However, if the reader wishes to compare the relative merits of these two types of illumination, let him compare Fig. 2 with Fig. 5, although they are not at the same magnification. Furthermore, Fig. 3 was not taken of exactly the same field as Fig. 2.

The next part of the discussion concerns itself particularly with the magnifications as placed under the photomicrographs. He gives a table concerning Figs. 4, 5, 6 and 11, and for the reader's satisfaction we have set up the photomicrographic machine according to the conditions given for the above

plates, replaced the sample with the stage micrometer, and photographed the same for each set of conditions. These photographs are herwith reproduced so that the reader may measure the magnifications for himself with a millimeter scale.

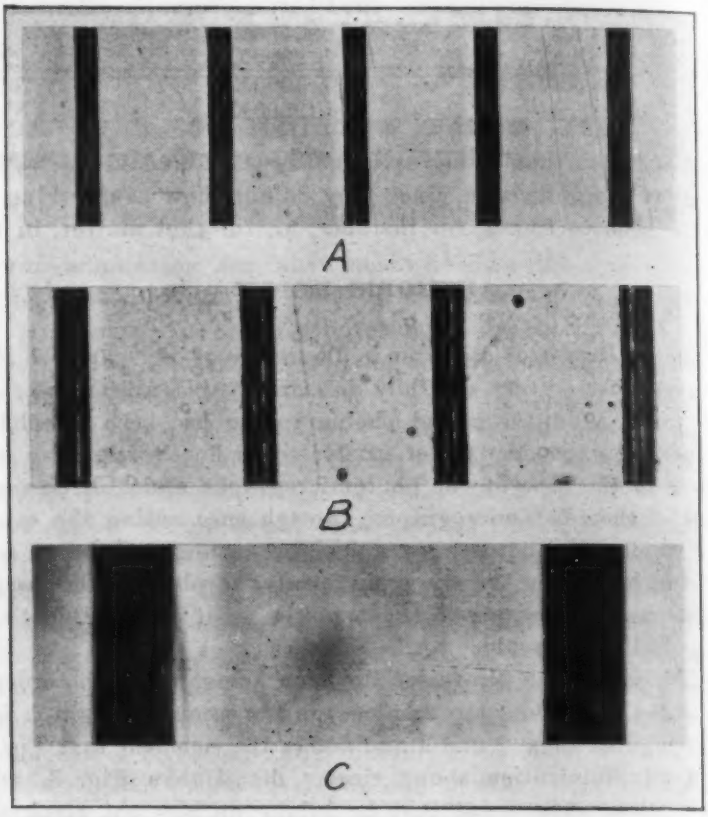


Fig. A—Photomicrograph of Stage Micrometer Taken of Divisions One One Hundredth of a Millimeter Apart. The Distance Between the Lines in Fig. A is 15 Millimeters, which is Equivalent to 1500 Diameters. Fig. B Shows the Same Lines Having a Distance Between Them of 21 Millimeters, which is Equivalent to 2100 Diameters Magnification. Fig. C Shows the Same Lines Having a Distance Between Them of 50 Millimeters, which is Equivalent to 5000 Diameters Magnification.

Fig. A, which corresponds to Fig. 4, and was taken under identical conditions, measures 15 millimeters which, when multiplied by 100, gives 1500 diameters. Fig. B corresponds to Fig. 5 and measures 21 millimeters, or 2100 diameters. Fig. C corresponds to Fig. 6, which seems to have given the most concern, measures exactly 50 millimeters or 5000 diameters.

I agree with Professor Boylston, however, in that certain points taken on Figs. 4, 5 and 6, when measured and compared with the magnifications given, do not correspond; however, I am at a loss to know just how this condition occurred, and can only imagine that Fig. 5 was not the photograph that should have been put over the conditions as given for it. Nevertheless, the conditions as given and the magnifications accompanying them are, as will

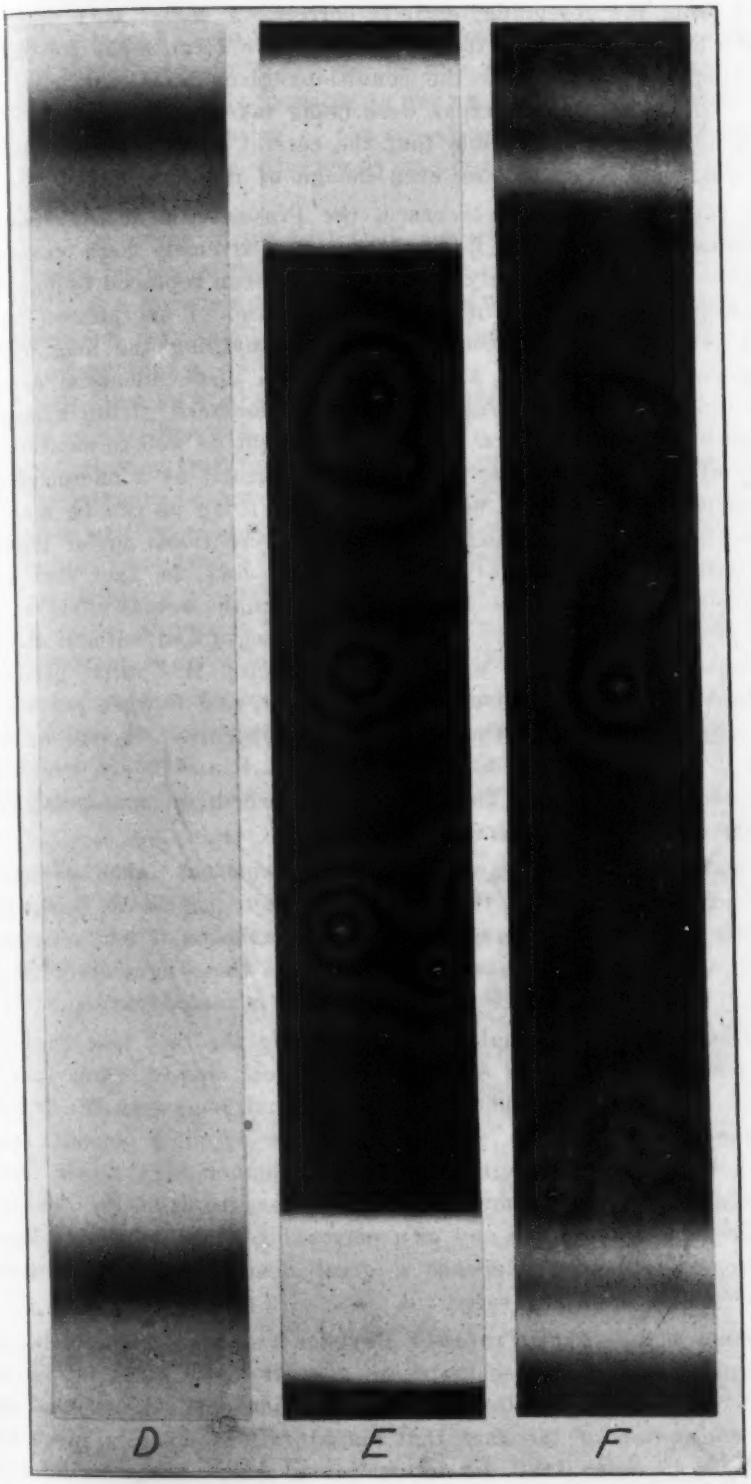


Fig. D—Shows the Same Lines as Shown in Figs. A, B, and C Magnified to 12,600 to 12,700 Diameters Magnification. The Distance Between the Lines in These Figures is 126 to 127 Millimeters.

be seen from the foregoing, entirely correct. I regret very much that this condition has occurred, and the only explanation I can make for it is that the correct photomicrograph for the conditions given must not have been published. While these micrographs were being taken, a great many others were run off, and it is just possible that the correct one was replaced by one intended for some other purpose even though of the same field.

As far as Fig. 11 is concerned, the Professor is entirely wrong in his calculations. Inasmuch as it was the only extremely high powered photomicrograph taken, it certainly could not have been replaced by one of a lower power through any mistake of ours or otherwise. I am pleased to say that Fig. 11 is correct in magnification, and if anything the magnification will measure more than given. Fig. D was taken under identical conditions as Fig. 11 and actually measures 126 to 127 millimeters, giving a magnification of 12,600 to 12,700 diameters. However, it might be well to mention here that an error of 100 dameters or so in the measurement of a micrometer scale at 12,000 diameters or more is not an uncommon thing as can be seen from the photomicrographs. The Figs. D, E and F were taken under identical conditions with the exception of the illumination and the fact that an inverse effect is obtained upon Figs. E and F, whereas the actual effect as shown in Fig. 11 is shown in Fig. D. Fig. F was photographed without the use of a filter whereas Fig. E made use of the Wratten "H" filter, giving a plate much sharper and easier to measure. Figs. E and F were purposely taken with a view to reversing the colors of the objects. It will be noted the lines or divisions on the micrometer in Figs. E and F are white, while in Fig. D they are black. This was accomplished by manipulation of the illumination and not by filters.

In addition I might say that Fig. 11 was not taken of any of the pearlitic areas shown upon the other photomicrographs, it being in reality made from an entirely different sample. Nevertheless, I will reiterate that I am very much pleased to know that a check on these figures reveals the fact that Fig. 11 is actually above 12,500 diameters in magnification.

Professor Boylston's final remark regarding the fact that Figs. 5, 6 and 11 are excellent examples of empty magnification, simply means that in these three figures as the enlargement of the original image of the objective increases, the depth decreases. But it is a matter of one's personal opinion regarding so-called empty magnification, and whether high power photomicrography means anything or not. The closing paragraph of the January paper now under discussion reveals my own personal feelings regarding high power photomicrography, and it depends a great deal upon the individual as to whether or not it is of any value.

I do not believe that Professor Boylston's comment should be taken as absolute in its meaning, since there are a great many other people who feel just the opposite and believe that magnifications above the usual or orthodox conception of the fact that magnifications using a given objective should never be over 1500 diameters (even when using an apochromatic objective with a 2-millimeter focal length, 1.40 numerical aperature, oil immersion), nevertheless, I feel that it is possible to enlarge by single pro-

jection to advantage. There is a certain amount of correctness to the statement that all that is seen in Fig. 5 can be seen in Fig. 2; however, as far as that is concerned, it might be possible to see as much in Fig. 7 which is very close to the actual magnification of the objective itself. Nevertheless, it is a fact that what is seen will not be nearly as apparent as it will be in some of the high power plates.

It is not a question of the fact that one sees more, because enlargement by projection or by ocular does not increase the number of visible objects in the field, but it is a question as to whether or not it is more advisable to study a field which has a very small number of constituents in it and those enlarged to such an extent that their characteristics are greatly emphasized. One of the great difficulties in studying structures under the microscope is that *too much* is seen rather than not enough; and there are very few people who can honestly say that they truthfully can pick out and name every constituent that is seen in the ordinary photomicrograph, even of simple substances. And there are still fewer who know anything about the mechanism of the formation and reasons for the formation of these constituents; and consequently it seems that it is much better to study a field enlarged as much as it is practically possible by single projection and narrowed down to as small an area of the sample as possible, to be able to better understand what is seen.

The above of course refers to an actual study of the mechanism of structures and not to an interpretation of some general specific trouble that has occurred in the material.

I should like to add in closing that it should be the practice of every metallurgist and metallographist to first study a given sample at the lowest powers possible, then at an intermediate power using for enlargement a combination which would yield a field of maximum resolution as well as of maximum area. Lastly, a combination of objective, ocular and camera extension which would yield a field of maximum resolution and maximum practicable enlargement or magnification with a minimum area.

R. G. GUTHRIE.

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested To Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 155. *Is it more advisable to cool an ingot from melting temperature down to room temperature before reheating for forging or to cool it down to 1000 degrees Fahr. and then reheat to forging temperature?*

QUESTION NO. 156. *What is the cause of "stickers" in the rolling of sheets from low carbon, basic open hearth steel sheet bar?*

QUESTION NO. 157. *Does 0.07Q to 0.090 per cent phosphorus in low carbon basic open hearth steel tend to prevent "stickers" in the rolling of sheets? If so, what is the explanation for such a tendency?*

QUESTION NO. 158. *What is the present recognized cause for the "transverse fissure" as occasionally found in rails?*

QUESTION NO. 159. *What is the explanation for the retarding effect on corrosion of small amounts of copper in low carbon steel?*

ANSWERS TO QUESTIONS

QUESTION NO. 134. *What are the usual feeds and speeds used in machining both carbon and alloy automotive steels, when using high speed steel cutting tools?*

QUESTION NO. 137. *What is the mechanism of the iodine etch for the deep etching of steel?*

QUESTION NO. 138. *Is the electrolytic pickling process being used to show up defects in steel bars? If so, how does it compare with the regular pickling processes?*

QUESTION NO. 142. *What is the consensus of opinion of the cause of blisters in low and high grade steels sheets?*

QUESTION NO. 143. *How can these blisters be eliminated?*

QUESTION NO. 144. *Why do many chromium-nickel steels show a laminated structure when viewed under the microscope?*

ANSWER, By G. F. Comstock, metallurgist, 967 Harrison Ave., Niagara Falls, N. Y.

The answer to Question No. 144 in May TRANSACTIONS does not, in my opinion, give a true idea of the cause of laminated structure in chromium-nickel or other steels. Through the work of Stead, Howe, and Sauveur, the cause of this structure is not "unknown" at the present time, but it has been shown to be due to dendritic segregation in the ingot. The cores of the dendrites are relatively pure metal, and the impurities are concentrated to a certain extent in the interstices between the dendrites. When the ingot is rolled, this heterogeneous structure is squeezed into a streaky form, with alternate bands of more or less pure metal. Diffusion at high temperatures has a tendency to make the structure uniform, but the non-metallic inclusions of course do not diffuse, and certain elements like phosphorus and nickel diffuse very slowly. It has been shown that carbon is expelled from the high-phosphorus streaks during recrystallization at the critical points, and the banded arrangement of the pearlite particles is readily explained in this way. Phosphorus is not the only element which causes dendritic segregation to persist in the form of bands in rolled steel. However, a low average phosphorus content in the steel, even down to 0.025 per cent or less, does not indicate that its distribution is uniform, or that narow bands of much higher phosphorus content may not exist in the steel, causing ghost lines and a streaky arrangement of the pearlite.

QUESTION NO. 147. *Is it desirable or necessary to periodically anneal the chains used on cranes? If so, why?*

QUESTION NO. 148. *What is the relative proportion of basic open hearth and acid open hearth steel being produced at present, and is there a trend toward increased relative production of either?*

ANSWER. By F. T. Sisco, metallurgst, Air Service, War Department, McCook Field, Dayton, Ohio.

The production of acid open hearth steel is about 4 per cent of the total open hearth tonnage and about 3 per cent of the total steel tonnage. Exact figures for the year 1924 may be secured from one of the trade journals, The Iron Age or Iron Trade Review.

There is a slight trend at present toward a decreased tonnage of acid open hearth steel. Part of the loss in acid tonnage is due to substituting basic open hearth steel for acid open hearth steel and part to substituting electric steel for the acid open hearth product.

As neither phosphorus nor sulphur is removed in the acid process, and as the supply of scrap and pig iron suitable for acid steel is limited and commands a higher price, acid open hearth steel cannot compete with basic steel for rails, plates, structural shapes, which make up the bulk of steel tonnage.

Acid open hearth steel is generally considered to be of better quality than basic steel. This is due to the characteristics of the acid slag which contains a much smaller amount of free oxides than the basic slag. Thus acid steel may be more thoroughly deoxidized in making. In addition the

acid slag has a higher surface tension than the basic slag, another important feature in the production of fine steel. The acid process is used for steels in which quality is paramount such as alloy steels for ordnance, guns, armor plate, and the like; and for fine alloy automotive steels, tools, etc. In this field it has been partly supplanted by the basic electric process which produces high quality steel and in addition removes phosphorus and sulphur. In the next 15 years the tonnage of acid open hearth steel will probably drop to about 1 per cent of the total tonnage.

QUESTION NO. 149. ***Do plates of basic open hearth steel ever have a higher base rate than acid open hearth steel?***

QUESTION NO. 151. ***What effect does the temperature of an oil-quenching bath have upon the hardness of a piece of steel quenched into it from the proper hardening temperature?***

QUESTION NO. 152. ***Is manganese up to 1.50 per cent detrimental in a steel to be used for carburizing purposes? How does the high manganese content affect the final product?***

QUESTION NO. 153. ***What is meant by acid and basic steel?***

ANSWER. By J. M. Wilson, 1243 Russell St., Allentown, Pa.

Acid steel derives its name from the lining of the furnace in which it is melted, and the composition of the slag. The lining, up to the slag line and bottom of the furnace is silica (sand), which, when heated up to a temperature slightly above the normal temperature for melting, the steel will glaze over or "set", making a smooth bottom and lining. The impurities in the scrap used for making acid steel, (phosphorus and sulphur) are not removed in the acid process. Therefore, the scrap and pig iron used must be low in these elements in order that the steel will finish within limits, which for most specifications is below 0.050 per cent for both phosphorus and sulphur.

Basic steel also derives its name from the furnace and composition of the slag used. The lining and bottom is of dolomite, which is a compound of magnesium and calcium with carbon dioxide, and is usually mixed with some of the basic slag.

Limestone is first charged into the furnace and then the pig iron and scrap. After the charge is melted and the temperature of the furnace is high enough, the limestone is broken up into calcium oxide and carbon dioxide. The calcium oxide being a base, combines chemically with acid elements or compounds, that is, silica, phosphorus and sulphur, etc. This basic slag forms a covering over the melted steel, and if the furnace conditions are correct, this basic slag usually retains most of the phosphorus and considerable sulphur. Both elements finish much lower than in the acid process.

Silica bricks are used in building the furnace for the acid process, and the bottom and sides in the basic process are made of magnesium brick up to a few feet above the slag line and the rest of the furnace is usually

composed of silica brick. Ordinarily a course of neutral brick such as chrome brick separates the basic brick of the bottom and sides of the hearth from the side walls which prevents in a large measure too rapid destruction of the walls by the slag.

ANSWER. By F. T. Sisco, metallurgist, Air Service, War Department, McCook Field, Dayton, Ohio.

The terms acid and basic applied to steel refer to the chemical characteristics of the refining process. At steel making temperatures the common refractories and fluxes have an acid or basic reaction. Silica (SiO_2) is the anhydride of the various silicic acids and acts as an acid at high temperatures. The basic refractories and fluxes, magnesite (MgO), dolomite (MgO.CaO), and lime (CaO) will react with silica at steel temperatures according to the reaction:

$$CaO + SiO_2 \rightarrow CaSiO_3$$

The various refractories and fluxes, silica, magnesite, dolomite, lime, etc., melt at very high temperatures (3300 degrees Fahr. or above) but the silicates formed by the reaction between a base such as lime and an acid such as silica melt much below steel making temperatures. Hence, if a furnace is lined with a basic refractory the slag used for refining must contain an excess of bases. If an uncombined acid such as silica is present in the slag it will react with the lining at those places where the two come into contact, and will rapidly destroy it.

A base such as lime has the property of reacting with the oxide of phosphorus (phosphoric acid, P_2O_5) forming calcium phosphate, a stable compound held by the slag. Thus phosphorus is removed from the steel in a basic process. Some sulphur is also removed. An acid such as silica will not react with phosphoric acid hence in an acid process phosphorus (nor sulphur) is not removed.

For additional characteristics of the basic and acid slag, see answer to Question No. 148.

QUESTION NO. 154. *What are the advantages of nickel steel versus chromium-nickel steel for carburizing?*

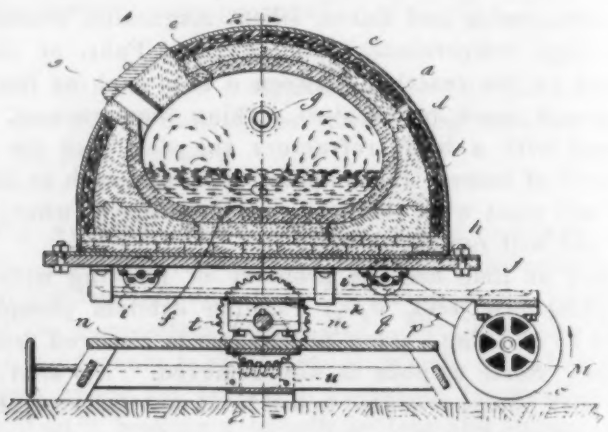
Reviews of Recent Patents

By
NELSON LITTELL, Patent Attorney
110 E. 42nd St., New York City
Member of A. S. S. T.

1,531,811, Electric Furnace, Fredolf J. Peterson, of Detroit, Michigan.

This patent relates to an improvement in electrical furnaces whereby a better mixing of the materials in the bath may be obtained. It is especially adaptable for melting alloys containing metals of widely different specific gravities.

The furnace comprises an oval-shaped chamber f, with the ends curved up at a sharp inclination. The furnace is rocked on a pivot m for tilting,



and is mounted for reciprocation on a track j by means of wheels i moving on the track. A motor M drives a pitman p to reciprocate the furnace back and forth on the track, and at each end of its motion there is a sudden reversal, so that the material at the bottom of the bath runs up the side wall, turns over, and drops back into the bath near the center, causing the heavier materials which have segragated at the bottom of the bath, to fall down through the lighter materials at the top, thus effecting the most efficient mixing of materials. The arrows indicate the path of the molten metal in the chamber, which is substantially a figure 8 in its movement. Electrodes g enter through each side of the furnace. A hand wheel is provided for tipping the furnace when it is to be tapped.

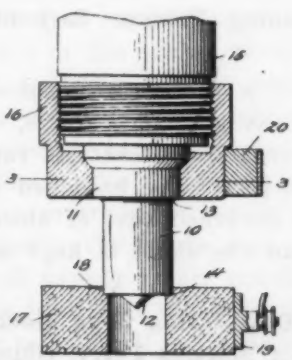
1,532,663, Treatment of Molten Baths, Porter W. Shimer, of Easton, Pennsylvania.

This patent describes a method of revivifying or reactivating case hardened baths, in which calcium cyanamide is used as the activating material. After some use, these baths lose their case hardening properties, due to contamination or impurities therein, and can be revivified by the addition of sodium cyanide to the bath. Preferably, the sodium cyanide

is added in powdered condition, using about one pound or less of the cyanide to a bath containing about 100 pounds of the molton case hardening mixture.

1,533,236, **Process of Locally Heat-Treating Hardened-Steel Articles, Thomas C. Dawson, of Bethlehem, Pennsylvania, assignor to Bethlehem Steel Company, of Bethlehem, Pennsylvania, a corporation of Pennsylvania.**

This patent relates to a process of locally heat-treating carbon steel articles, such as the punch 10 which comprises connecting the electrode 20 of an electric furnace to the holder for the punch, putting another electrode 17 in contact with the end of the punch, passing a current between these electrodes to heat the punch, and rotating the punch by means of the



holder 15, so as to provide for uniform heating. When the desired temperature has been reached, the current is cut off and the punch is quenched in a suitable cooling medium.

1,535,317, **Process of Annealing Steel Sheets, Irvin John Koehnline, of Bridgeport, Ohio, and Samuel Peacock, of Wheeling, West Virginia.**

This patent relates to a process of annealing sheet steel, whereby, after finishing in cold rolls, the sheets may be annealed at a temperature high enough to prevent Stead's brittleness, without welding together and without detrimentally affecting the surface. According to the invention, the steel sheets are given a thin coating of calcium or magnesium hydroxide, as by spraying or dipping, and then stacked and annealed at around 800 degrees Cent. The use of hydroxide prevents welding of the plates, and also neutralizes to a certain extent acid used in the pickling bath.

1,535,549, **Rust-Resistant Iron, Harry A. Schwartz, of Cleveland, Ohio, assignor, by mesne assignments, to National Malleable and Steel Castings Company, of Cleveland, Ohio, a corporation of Ohio.**

This patent describes a rust-resistant malleable iron casting containing 0.15 per cent to 0.25 per cent of copper and having the usual percentage of carbon, manganese, silicon, and the like. Within these percentages, copper forms an alloy with the iron which greatly increases its rust-resisting properties. If in excess of 0.25 per cent free copper remains in the casting which sets up an electrolytic action with the iron, which results in more rapid rusting, than would be the case if no copper was added.

1,536,028, Method of Making Strip Sheets, Harry M. Naugle and Arthur J. Townsend, of Canton, Ohio.

This patent relates to a method of finishing sheet steel or strip sheets after the cold rolling operation.

The inventors say that the ordinary box annealing is unsatisfactory, because it results in over-annealing of the outer portions of the sheets and the production of a grain growth, which destroys the ductility and uniformity of the mass. They therefore use an open and continuous annealing method for the individual sheets, passing them through a tunnel heated to a temperature of about 1200 to 1400 degrees Fahr. in a cycle of 40 minutes or less.

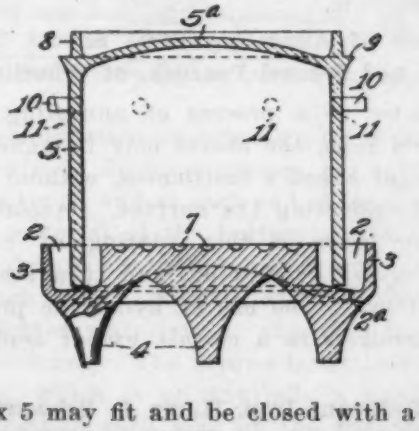
1,536,416, Steel-Hardening Process, Richord Bischoff, of Dusseldorf, Germany.

This patent relates to a process of hardening parts of shafts, subjected to most wear, such as journal bearings, crank shafts and the like.

According to the invention, the shaft is rapidly rotated between the points of a lathe, and the part to be hardened is heated by the jet flame of a welding burner to a hardened heat of about 800 degrees Cent. The jet is then withdrawn, and the shaft is kept in rotation until cooled in the air.

1,536,438, Annealing Box, Irving John Koehnline, of Bridgeport, and William Earl Armstrong, of Martins Ferry, Ohio.

This patent relates to an annealing box, comprising a base plate having legs 4 and having a groove 2 around the edges thereof into which



the bottom of the box 5 may fit and be closed with a sand seal. The box has an arched top 5^a and a rim 8 and ledge 9 around the top. The rim and ledge are used to support a sand or clay blanket over the top of the box, which protects the same from heat and from any impinging flames. Suitable lugs 10 and 11 are provided for handling the box.

1,536,653, Method of Making Silicon Steel, Vere B. Brown, of Brackenridge, Pennsylvania.

This patent relates to a method of making silicon steel containing manganese, which comprises reducing the manganese from manganese ore in the ladle, without the use of ferro-manganese or other manganese alloys

which tend to increase the carbon content of the finished steel. The manganese ore is used in excess of the theoretical amount necessary to give the desired manganese content. It is preferable to mix a small amount of fluorspar with the manganese ore before it is added to the ladle to promote fluxing out of the free manganese oxide.

1,536,655, **Method of Manufacturing Steel Sheets, Vere B. Brown, of Brackenridge, Pennsylvania, assignor to Valley Holding Corporation, of Brackenridge, Pennsylvania, a corporation of Pennsylvania.**

This patent relates to the production of sheet steel for automobile and other stamping use, which is free from Stead's brittleness, and uses the following process: Sheet bars of the proper thickness are heated to rolling temperature and rolled to approximately 60 per cent of the length of the sheets required. They are then annealed, pickled to remove the scale, and cold rolled to an extent necessary to eliminate all superficial surface defects formed during the hot rolling. The sheets, after this cold rolling step, are matched, heated to a temperature suitable for rolling but low enough to avoid scaling, and then rolled to the length required. The second hot rolling step is carried on in a mill having highly polished smooth rolls, and since the surface of the plate is free from the usual defects due to the final hot rolling, it is not necessary to cold roll in the finishing operation. The omission of the cold rolling at the finishing operation avoids the occurrence of Stead's brittleness.

1,536,663, **Method of Manufacturing Steel Sheets, Otto Herron Cunningham, of Brackenridge, Pennsylvania, assignor to Valley Holding Corporation, of Brackenridge, Pennsylvania, a corporation of Pennsylvania.**

This patent relates to a method of manufacturing sheet steel for the automobile and metal furniture trades, and other fields in which there will be incurred difficult stamping operations.

It is the object of the invention to avoid the phenomenon know as "Stead's brittleness", which often occurs when sheets have been finished by cold rolling and annealed at a low temperature. According to the usual practice, these sheets are rolled from bars to approximately the final length by hot rolling, annealed, pickled to remove the scale, cold rolled to get the desired finish without any substantial reduction in thickness, and subsequently re-annealed at a low temperature. The low temperature anneal is necessary to preserve the smooth finish and to prevent welding of the plates together in the box if annealed at normalizing temperatures. Various researches have shown that if low carbon steel is subjected to cold roll reduction, Stead's brittleness will not occur, even though the steel is annealed at a temperature below the normalizing temperature. The present inventor, therefore, hot rolls the bars to a length at least 10 per cent less and a thickness at least 10 per cent greater than that required in the final product, anneals, pickles, and then reduces the sheets at least 10 per cent in the cold rolling, then anneals at a low temperature, producing a sheet having the desired finish without Stead's brittleness.

Abstracts of Technical Articles

Brief Reviews of Publications of Interest to Metallurgists and Steel Treaters

DESIGNING THE PICKLING DEPARTMENT FOR ECONOMY IN MAINTENANCE. By C. A. Crawford, International Nickel Co., New York City, in *Iron Trade Review*, April 9, 1925.

The above is the second of a series of three articles dealing with pickling practice and equipment. This article states that in tank construction, rods should be acid resistant; also the size of the thread is important. An improved method of bolting plungers and partitions is also described.

THE PRINCIPLES OF DIE-CASTING. By H. C. Skinner, general manager, Franklin Die-Casting Corp., Syracuse, N. Y., in *American Machinist*, April 9, 1925.

This is the fifth and concluding article on this subject, and deals with the use of inserts in die-casting; methods of constructing. Examples of castings made with inserts successfully employed are given.

MAKING HIGH SPEED TWIST DRILLS. By Avery E. Granville, in *Canadian Machinery*, April 16, 1925.

This article describes the manufacture of the drill from the bar stock. A number of illustrations of the process of manufacture are included.

PEEP INTO CUPOLA WHEN MELTING STEEL. By J. Grennan, instructor in foundry practice, University of Michigan, Ann Arbor, Mich., in the *Foundry*, April 15, 1925, page 314.

This article was presented at the Milwaukee convention of the American Foundrymen's Association and give the results of experiments conducted at the University of Michigan, on this phase of melting and what actually happens when steel is melted in a cupola.

GAS TAKES CHARGE OF HEATING IN THE RAILROAD SHOP. By J. H. Gumz, Pacific Gas and Electric Company, in *Gas Age-Record*, April 18, 1925, page 571.

This article tells the story of one railroad where the use of gas has been instrumental in effecting the postwar operating conditions, and states that improved methods and new processes in the shops has been one of the many things that has brought about this rejuvenation. Interesting cost data for various processes is given.

MAKING HARD MANGANESE STEEL. By Hubert Hermanns and Hermann Meixner, in the *Foundry*, April 15, 1925, page 323.

The above article states that hardness and dependability of the steel is contingent upon the manganese content; also the loss of oxidation is reduced when ferrromanganese in the molten state is added. Thick wall castings are discussed.

CLOSER ELECTRODE CONTROL. By H. R. Crago and J. A. Seede, industrial engineering department, General Electric Co., Schenectady, N. Y., in *Iron Age*, March 12, 1925, page 763.

The authors of this article describe a new automatic device for electric are furnaces which embodies all the desirable features of the old type in addition to several new features which are incorporated to make the control closer and more flexible, also to make the operation simpler from the standpoint of the operator.

HARDNESS NUMBERS AND THEIR RELATION. By Dr. H. P. Hollnagel, department of physics, General Electric Co., Lynn, Mass., in *Iron Age*, March 12, 1925, page 770.

The first half of this article was published in the November 27, 1924, issue of *Iron Age*, and reviewed the ideal physical state of metals. In this portion the author states that it is believed that to ascertain satisfactory relations between hardness numbers from a physical standpoint, they must be reduced to a common language, that is, work per unit volume per unit strain. The problem is not how to make a new device or obtain new nomenclature but how physically to ascertain the quantities necessary to establish correlations precisely. This does not in any way prevent the continuation of the present use of hardness measuring devices more particularly as they are often used for specific purposes, that is, in the measuring of specification numbers.

PREFERS ELECTROLYTIC ETCHING FOR METALS. By Frank Adcock, in *Foundry*, March 15, 1925.

This paper was presented at a meeting of the British Institute of Metals, Birmingham, England, and states that many reagents applied to the polished surface of cold metals produce irregular etchings which lead to confusion in metallurgical investigations. It points out the results of etching solutions of citric acid and ammonium molybdate on different metals. The electrolytic process of etching was found to give close regularity and rather uniform results.

OPERATING EXPERIENCES IN PULVERIZED FUEL. In *Mechanical Engineering*, Vol. 47, No. 4, 1925, page 271.

At the joint meeting of the Cleveland Engineering Society and the Cleveland sections of the American Society of Heating and Ventilating Engineers and the American Society of Mechanical Engineers, held in Cleveland in January, 1925, John Wolff presented a paper on "Pulverized Coal in Large Boilers." In connection with this paper, P. W. Thompson, chief assistant

engineer, power plant, Detroit Edison Co., and E. H. Tenney, chief engineer, power plants, Union Electric Light and Power Company, presented extended discussions on operating experiences with their companies' plants.

PROPERTIES OF MATTER UNDER HIGH PRESSURE. By P. W. Bridgman, professor of physics, Harvard University, in *Mechanical Engineering*, Vol. 47, No. 3, 1925, page 161.

The above paper was a lecture delivered at the annual meeting of the American Society of Mechanical Engineers, New York, December, 1924, and gives the results observed when using hydrostatic pressures of the order of several hundred thousand pounds per square inch. The methods of packing and of measuring pressures are discussed, as well as conditions under which materials rupture under high pressure.

HARDNESS TESTERS. In *Mechanical Engineering*, Vol. 47, No. 4, 1925, page 282.

At the recent annual meeting of the American Society of Mechanical Engineers, a session was devoted to research in machine design and operation under the auspices of the research committee on cutting and forming of metals, at which B. H. Blood, general manager, Pratt and Whitney, Hartford, and chairman of the committee, presided. J. O. Keller, professor of industrial engineering, Pennsylvania State College, presented a paper entitled, "Comparison of Herbert Pendulum Hardness Tester with Other Hardness Testers," in which he described the Herbert hardness tester and a set of tests made with it and other testers by which comparative results had been obtained and analyzed. J. K. Woo, consulting engineer of New York, and chairman of the special research committee on metal springs, also presented a preliminary progress report of the committee. O. W. Boston, assistant professor of shop practice, acting director of shops at the University of Michigan, made a brief report on research work in the cutting of metals. He spoke of having visited the laboratories of Professor Coker at the University College at London. Professor Coker has done some very creditable work in cutting nitrocellulose with a glass tool, examining the material being cut as well as the tool with polarized light, and determining the stresses. He claimed that the results of his experiments were applicable to steel and cast iron because these metals, like nitrocellulose, had uniform values of heating below the elastic limit. This, however, was a question yet to be proved, because it was known that the formation of a chip was a result of stress beyond the elastic limit, and whether steel and nitrocellulose were similar beyond the elastic limit is still to be determined.

News of the Chapters

STANDING OF THE CHAPTERS

IN the May issue of TRANSACTIONS appeared the relative membership standing of the 29 chapters of the Society as of March 1, 1925, and as of April 1, 1925. The tabulation which appears below shows the relative membership standing of the chapters on April 1, 1925, and on May 1, 1925.

Standing as of May 1

GROUP I	GROUP II	GROUP III
1. DETROIT (298)	1. Hartford (127)	1. Tri City (68)
2. Cleveland (297)	2. Lehigh Valley (108)	2. Rochester (62)
3. Pittsburgh (275)	3. Golden Gate (102)	3. Los Angeles (60)
4. Chicago (266)	4. CINCINNATI (74)	4. WASHINGTON (52)
5. Philadelphia (255)	5. Milwaukee	5. New Haven
6. Boston (229)	6. Syracuse	6. SCHENECTADY
7. New York (209)	7. ST. LOUIS	7. Worcester
	8. Indianapolis	8. Rockford
	9. Buffalo	9. Providence
	10. Northwest	10. Springfield
		11. TORONTO
		12. South Bend

Standing as of April 1

GROUP I	GROUP II	GROUP III
1. Cleveland (295)	1. Hartford (127)	1. Tri City (66)
2. Detroit (288)	2. Lehigh Valley (111)	2. ROCHESTER (62)
3. Pittsburgh (272)	3. Golden Gate (102)	3. Los Angeles (56)
4. Chicago (266)	4. Milwaukee (74)	4. New Haven (52)
5. Philadelphia (251)	5. Cincinnati (73)	5. Washington (50)
6. Boston (228)	6. Syracuse	6. Worcester
7. New York (206)	7. Indianapolis (28)	7. Schenectady
	8. St. Louis	8. Rockford
	9. Buffalo	9. Providence
	10. North West	10. SPRINGFIELD
		11. South Bend
		12. Toronto

GROUP I. Congratulations to Detroit! This progressive chapter again heads the group, and becomes the largest chapter in the Society. While the

margin over Cleveland is but one, nevertheless, that was sufficient to place them in position 1, and it is now a contest between Al Grinnell, chairman of the Detroit chapter membership committee and his faithful workers, and Joe Emmons, chairman of the Cleveland chapter membership committee with his active cohorts. With the exception of the first two, the other chapters remain practically in the same position, although Philadelphia and Pittsburgh each had 7 new members while New York came along with 5.

GROUP II. This group remains as in the last month's report, except that Cincinnati forges ahead of Milwaukee, and St. Louis changes places with Indianapolis.

GROUP III. This group had three changes, Washington advancing from fifth to fourth place, Schenectady from seventh to sixth, while Toronto moves from twelfth to eleventh position.

There were a total of 93 new and reinstated added to the rolls of the Society for April. However, on the month the Society showed a net gain of but 19, 21 having resigned and 53 were dropped for non-payment of dues. This cut down rather heavily on some of the chapters in all of the groups, and had a tendency to decrease greatly what otherwise might have been a very desirable and creditable gain.

BOSTON CHAPTER

THE April meeting of the Boston chapter of the American Society for Steel Treating was held Thursday evening, April 23, 1925, at the Walker Memorial Building of the Massachusetts Institute of Technology, Cambridge. The meeting was preceded by an excellent supper with a rather small attendance, probably due to the exceptionally fine spring weather.

At 7:30 p. m. the meeting was called to order and R. L. Sanford, physicist and chief of the magnetic laboratory, Bureau of Standards, Washington, D. C., delivered an extremely interesting talk on the subject "Magnetic Testing" illustrated with the lantern slides. Mr. Sanford explained in the most understandable manner, the principle of the magnetic phenomenon, its action on steel and its relation and effects to the change in the structure of the steel. He then illustrated with lantern slides, and discussed the work that had already been done towards getting together the necessary information required to make use of this valuable method of testing. Mr. Sanford pointed out that it was a matter of securing a tremendous amount of data before this method would be usable to the general public, comparing the amount of work necessary to that required in the development of such an art as chemistry. In other words, the results obtained so far have thoroughly proven the possibility of the method but that the interpretation of the results depended upon a great deal of elementary experiments and hard work.

A very interesting discussion followed and the meeting was closed with a vote of thanks to Mr. Sanford in an expression of our appreciation of the amount of work that has been done on this method of testing.

Preceding the principal speaker of the evening, there was a short busi-

ness meeting and the secretary read the nominations for officers to be elected at the May meeting and also called the attention of the members to the Sectional Meeting at Schenectady May 28, 29 and 30. S. W. Parker, chairman of the program committee, outlined the plans for our June outing which we hope will be held at Pemberton on the shore and will include a boat ride with shore dinner and athletic sports. *G. S. Davis.*

Meeting: May 22, Walworth Manufacturing Company.

Subject: "Giving Steel Tools a Chance,"—F. R. Palmer, Carpenter Steel Co., Reading, Pa.

Meeting to be reported in the next issue of TRANSACTIONS.

BUFFALO CHAPTER

The April meeting of the Buffalo chapter was held April 27, 1925, at the Hotel Buffalo. The meeting was called to order by Mr. Armstrong. No business of the Society was put before the chairman so the speaker was introduced at once.

Professor H. M. Boylston of the Case School of Applied Science was the speaker for the evening, and he chose as his subject "The Historical Features of the Iron and Steel Industry." The lecture was illustrated by a large number of slides.

One very important fact brought out during the evening was that iron is one of the oldest metals to be used by man. The principal part of the lecture was the illustrating of the manufacture of iron from the beginning to the present time.

About forty members and guests were present.

CHICAGO CHAPTER

The last regular meeting of the year, held May 14 at Ryerson Physics Laboratory, University of Chicago, was featured by Dr. H. B. Lemon speaking on the Past, Present, and Future of the Science of Physics.

The attention accorded the unusually interesting and appealing speaker bespoke the interest of a record attendance at this meeting as regards fundamental sciences.

Dr. Lemon pointed out the potent fact that the twentieth century is the acid test of science and predicted, in the words of his chief, Dr. Michaelson, that the future of physics was to be found in the fourth and fifth decimal places. He emphasized the point that the only theory that had weathered the test of this century so far was the kinetic theory of heat which, if anything, had been reenforced and entrenched.

The latter part of his talk, which was illustrated by moving pictures and actual laboratory experiments, was devoted to speculation in the field of physics and to philosophical discussion.

It is the proper appreciation of the importance of fundamentals that is leading this chapter to dwell more and more on this type of program.

At this meeting the following men were elected as officers of the chapter for the ensuing year:

Chairman—Robert G. Guthrie, metallurgist, Peoples Gas Light & Coke Co., 122 South Michigan Avenue, Chicago.

Vice-Chairman—E. J. Janitzy, metallurgical engineer, Illinois Steel Company, South Chicago, Illinois.

Secretary-Treasurer—Arthur G. Henry, sales engineer, Perfection Tool Hardening Co., 1742 West Austin Avenue, Chicago.

Members of the Executive Committee—C. L. Colwell, metallurgist, Stewart-Warner Corporation, 4535 Fullerton Ave., Chicago. W. A. Edwards, district manager Ludlum Steel Co., 1238 W. Washington Blvd., Chicago. Wm. Finkl, metallurgist, A. Finkl & Sons Co., 1326 Cortland Street, Chicago. David Levinger, superintendent of development, Western Electric Co., Hawthorne Station, Chicago. R. R. Smith, sales metallurgist, United Alloy Steel Co., Room 1440, Strauss Bldg., Michigan Avenue, Chicago.

The chapter's annual outing will be held June 13 at Dixmoor Golf Club. The picnic will be opened at 2 o'clock with the traditional chicken dinner. The afternoon and early evening will be replete with an absorbing program featured by many prize-winning contests. A golf tournament has been arranged as an added attraction to those interested. There will be in all some $250.00 worth of prizes awarded.

CINCINNATI CHAPTER

Meeting: May 22, Literary Club Rooms.

Subject: "The Manufacture and Properties of Malleable Cast Iron,"—H. A. Schwartz, manager of metallurgical research, National Malleable & Steel Castings Co., Cleveland.

Meeting to be reported in the next issue of TRANSACTIONS.

CLEVELAND CHAPTER

Col. A. E. White, Director of Engineering Research, University of Michigan, was the speaker at the regular monthly meeting of Cleveland chapter, which was held in the ball room of Hotel Winton on Friday evening, May 15, 1925.

Colonel White's subject was "The Malleablizing of White Iron" and the paper presented was based on the report of an investigation conducted at the University of Michigan and made possible by the Detroit Edison Co. and the Saginaw Malleable Iron Co.

After covering briefly the manufacture, properties and structural constitution of malleable iron, the speaker described and summarized the research work which had been done. This chiefly concerned the effects of varying times, temperatures and cooling rates during the annealing process used in the manufacture of the malleable iron castings.

Many charts and micrographs were used in illustration. The speaker stated that the facts brought out through this research were probably already well known by manufacturers of malleable iron, but that the work done was nevertheless of considerable value as giving the results of a carefully conducted scientific investigation.

The summary of Colonel White's paper is as follows:

(1) The time required to produce equilibrium in iron carbon alloys of the composition commonly used in making malleable cast iron varies from less than 4 hours at 1800 degrees Fahr., with high silicon alloys to 275 hours at 1400 degrees Fahr., for medium silicon alloys and longer for low silicon alloys.

(2) The combined carbon for equilibrium conditions varies from 1.20-1.25 per cent at 1800 degrees Fahr., to 0.47-0.50 per cent at 1400 degrees Fahr., and is but slightly affected by the ordinary variations in silicon.

(3) The maximum cooling rate compatible with the successive maintenance of equilibrium was found to be 28 degrees Fahr., per hour for the lower cooling range (1500-1300 degrees Fahr.,) for 0.90 per cent silicon alloys and faster for the upper temperature ranges. For an 0.82 per cent silicon alloy, the rate varies from 25-30 degrees Fahr., at 1700-1600 degrees Fahr., down to 5-8 degrees Fahr., for 1400-1300 degrees Fahr.

The attendance at this meeting was about 60 and about 20 were present at the dinner which preceded it. *A. S. Townsend.*

DETROIT CHAPTER

Meeting: May 16, Ann Arbor, Mich.

Subject: "War Experiences,"—Hugh Cabot, Dean of the Medical School; and "Some Phases of the Iron and Steel Industry,"—W. W. Macon, managing editor of *Iron Age.*

Meeting to be reported in the next issue of TRANSACTIONS.

GOLDEN GATE CHAPTER

No report received

HARTFORD CHAPTER

At the meeting of the Hartford Chapter in the Hartford Engineers' Club Room on May 12, 1925, the following officers were elected: B. S. Lewis, chairman; R. W. Woodward, vice-chairman; E. D. Lambert, secretary-treasurer. Executive Committee: L. A. Lanning, R. F. V. Stanton, W. D. Fuller, W. T. DeWalt, C. W. Atwood.

W. E. Day, Jr., of the International Motor Co., New Brunswick, N. J., read a paper on "Carburization by Solid Cements."

The paper stated that the irregularities commonly encountered in commercial carburizing are due to empirical methods and lack of knowledge of the nature of the process. Consistency in results may be obtained by a study of the mechanism of carburizing and application of the findings to common practice.

From elaborate experiments the author has reduced the carburizing conditions to three groups—those which form proper gases, those governing the solution of carbon and those controlling diffusion of carbon.

Each of these groups may be studied separately and their individual and joint effects recorded.

A number of experiments are described in the paper and are illustrated with charts and photomicrographs.

All the theoretical work is shown to have practical application and comparatively simple tests are outlined which may be applied to commercial work. A number of the features of carburizing which require unusual consideration are called to attention.

In the discussion following the paper, Mr. Day was able from his experience to give very definite opinions on many questions asked about particular features of carburizing.

F. G. Hughes of the New Departure Mfg. Co. and one of the National A. S. S. T. directors told the chapter something of the way the national society is being run and of plans for the future. He drew a comparison to case hardened steel of the core of everyday common sense, intelligent but non-technical heat treatment and the refined case of highly trained and specialized theoretical work of the laboratory, both case and core being necessary and requiring proper treatment to secure best results.

The total attendance was 87, including 39 members and 48 guests.

It has not been customary in this chapter to keep any formal minutes of the proceedings of the chapter or of the executive committee.

We have held monthly meetings since September, 1924, and the average attendance as shown by the cards turned in is about 90, of which 35 were members and 55 guests.

The general topics presented in the form of papers were: September, "Grinding," C. H. Norton and H. W. Wagner; October, "X-ray Testing of Metals," General T. C. Dickson; November, "Commercial Heat Treating," Z. L. Sault; December, "Trend in Heat Treating Apparatus," F. J. Ryan and E. L. Wilson; January, "Steel for Small Tools," A. H. d'Arcambal; February, "Tool Steel Troubles," F. R. Palmer; March, "Heat Treating and Our Society," W. S. Bidle and W. H. Eisenman; April, "Malleable Iron," W. R. Bean. These meetings were held in the Hartford Engineers' Club rooms, with the exception of the November and December meetings, which were held in the Hartford Electric Light Co. auditorium.

For several years the Hartford chapter has made a practice of distributing prizes at the close of each meeting, the recipients being selected by drawing from cards which each member of the audience has been requested to fill in with his name and address. This year, three prizes having a value of about $2.00 each, were given at every meeting.

In this way we secure a good registration of all members and guests for our mailing list, and this practice also keeps certain members of the audience from leaving before the end of the meeting. Such early leaving disturbs the speaker and distracts the attention of the entire audience.

In June of last year this chapter had 135 members, but this has dropped slightly to 127.

The executive committee has held monthly meetings to plan the work of

the chapter and the various sub-committees have done valuable work. The program committee in particular have performed important and difficult service. *E. D. Lambert.*

INDIANAPOLIS CHAPTER

The May meeting of the Indianoplis chapter of the Society held on the 11th was well attended. Dinner was served at the Y. M. C. A. at 6:30 p. m. and the meeting was called to order by the chairman at 7:30 p. m. The first business was the report of the Nominating Committee. The Nominating Committee consisted of H. B. Northrup, chairman, J. Jones and C. A. Edwards. As a result of the recommendations of this committee Wm. G. Praed, Link Belt Company, was elected chairman, C. A. Edwards, 213 Liberty Building, vice chairman, and C. H. Beach, 1403 Merchants Bank Building, secretary-treasurer. The executive committee elected consists of the following members: W. L. Appel, John Jones, Axel Weydell and E. L. Roch. The Auditing Committee was appointed to audit the books of the secretary-treasurer. After the business meeting a round table discussion was held, many questions being answered. *H. A. Maves.*

LEHIGH VALLEY CHAPTER

No report received

LOS ANGELES CHAPTER

Meeting: May 6, Westinghouse Electric & Manufacturing Company.
Subject: "Refractories,"—E. H. Blausen, Johns-Manville Company.
Meeting to be reported in the next issue of TRANSACTIONS.

MILWAUKEE CHAPTER

No report received

NEW HAVEN CHAPTER

Meeting: May 22, Winchester Club House.
Subject: "High Speed Steel,"—J. P. Gill, metallurgist, Vanadium Alloys Steel Company.
Meeting to be reported in the next issue of TRANSACTIONS.

NEW YORK CHAPTER

J. H. Hall, metallurgist with the Taylor-Wharton Iron and Steel Company, gave a very interesting talk on Wednesday, May 20th, before the New York chapter of the American Society for Steel Treating. In this talk Mr. Hall dealt briefly but quite completely with each part of the subject.

The Taylor-Wharton Iron and Steel Company was founded about 1760, and is about the oldest company doing business today upon the continent of North America with the exception of the Hudson Bay Company. During this complete period they have been manufacturers of iron and steel. Mr. Hall believes that manganese steel was discovered by Mr. Mushet and co-workers when experimenting with Bessemer steel. Bessemer steel up to that time had been practically a failure since it did not possess suitable working qualities,

and this was remedied by the addition of sufficient amounts of manganese, which average around 2 per cent. Since 2 per cent manganese was found to give such desirable properties, Hadfield decided to determine the effect of greater amounts of manganese, and made steels, which contain as high as 20 per cent. The present manganese steel, known as Hadfield's contains from 1 to 1.40 per cent carbon, and 11 to 14 per cent mangenese.

It was found that the manganese steel did not respond to heat treatment in a manner similar to ordinary steel, and was quite brittle in the cast condition. It is claimed that the heat treatment was discovered by accident when some worker threw a piece of red hot manganese steel in cold water and upon later examination found it to have been materially toughened by this treatment. The proper treatment consists of heating to 1940 degrees Fahr. (1060 degrees Cent.) and quenching in cold water. It is necessary to quench from above 1650 degrees Fahr. (900 degrees Cent.) to keep the steel entirely austenitic. If quenched below 1650 degrees Fahr. (900 degrees Cent.) part of the austenite changes into martensite. It is necessary to heat at a temperature of 1940 degrees Fahr. (1060 degrees Cent.) to ensure complete solution of all of the cementite. Heat treated material has a Brinell hardness ranging from 180 to 200 with a tensile strength of 70,000 to 100,000 pounds per square inch, with an elongation in 2 inches of 15 to 20 per cent. The elastic limit was placed at around 30,000 pounds per square inch, but it is impossible, due to the nature of the steel, to obtain a drop of the beam and the stress strain diagram gives a continuous curve without a break which makes it difficult to obtain the elastic limit in this manner. It was stated that a large amount of experimental work would be put in during the coming year in determining the true elastic limit. A marked difference in properties is obtained due to the casting temperature. Material which is cast hot has a large columnar structure, while that cast on the cold side is very fine grained. It was stated that there would be a difference in tensile strength of 15,000 pounds per square inch between the metal cast cold and that cast hot. It is for this reason that the design of manganese castings is very important and should be taken up with the manufacturer before any definite decisions in design are made.

Although manganese steel is very tough and has high tensile values it exhibits very poor resistance to fatigue. Fatigues stresses cause cold working, and thus hardening of the outer fibers which break and so cause fatigue failure. It is very difficult to machine manganese steel and although it can be done it is very expensive and at the present time is not a commercial operation. All finishing has to be done by grinding.

Manganese steel has the unique and valuable property of becoming very hard when cold-worked. The outer layers which are the most severely worked become extremely hard and resistant to abrasive action, and being backed up by a very tough core gives it valuable shock and abrasive resisting powers. The limiting feature, however, is the fact that it must be used in connections where there are both cold work and abrasions. Abrasion without cold work causes the material to wear away rapidly due to lack of hardening, and cold work without abrasion causes the material to grow or spread out.

Several of the important uses were stated, such as frogs for railway work, and points for steam shovels, jaw crushers and the like. In cases where there is both cold work and abrasion manganese steel generally out-lives ordinary steel 15 to 1.

Many interesting cases were cited for both favorable and unfavorable working conditions. One of the most interesting was the failure of manganese steel to make a satisfactory car wheel, and it was for this purpose that the use of manganese steel was first introduced into this country. The failure was due to the fact that the tire which obtains a large amount of cold work but no abrasion becomes hard and spreads out gradually until it fins. The flange of the wheel is subjected to a great deal of abrasive action especially upon curves, but it receives very little cold work and for this reason quickly wears away.

Following his talk, Mr. Hall showed a motion picture of a very successful application for manganese steel for treads on caterpillar tractors. Many interesting questions were asked following the meeting concerning the theory for the hardening of the steel due to cold work which Mr. Hall stated was not definitely known at this time, but was thought to be due to the formation of martensite. The forging qualities were discussed and manganese steel can be forged readily providing very light reduction is made at a temperature of about 1832 degrees Fahr. (1000 degrees Cent.) for the first 10 or 15 per cent and then it can be reduced at a more drastic rate, but the heating should not exceed 2100 degrees Fahr. (1150 degrees Cent.) since above this temperature manganese steel is easily burned, and heat treatment will not return it to its original condition.

An interesting point brought out by Mr. Hall was the fact that equally as good steel could be made by the bottom blown Bessemer convertor as by the electric furnace. In fact, they obtained little or no difference in their quality. They have two convertors and one electric furnace in their plant, the electric furnace being used entirely for remelting scrap. He stated that the Taylor-Wharton Company manufactured one-third of the manganese steel in this country.

A large turn-out was present to hear this exceptionally well presented paper.

S. M. Norwood.

NORTHWEST CHAPTER

The annual meeting of the Northwest chapter was held at the Manufacturers Club of Minneapolis on May 12th with about thirty members present.

The report of the nominating committee was unanimously accepted The officers elected for the coming year are as follows:

Chairman, W. I. Sweet
Vice-Cairman, Norman Conn
Secretary-Treasurer, Alexis Caswell
Executive Committee,
H. Kenneth Briggs, F. G. Lilygreen,
C. M. Hope, Sidney J. Pfaff,
G. C. Priester.

The membership voted that the Manufacturers Club of Minneapolis be sincerely thanked for the hearty cooperation in the use of the club room and office staff.

At the close of the business session R. D. Malm, sales manager of the Lincoln Electric Company of Cleveland, Ohio, gave a most interesting talk on electric welding. He explained why the carbon electrode would enable a greater penetration in welding steel and how the electrode could be kept from carburizing the work. The well-known phenomenon that the positive terminal of the D. C. arc has two-thirds of the heat energy while the negative terminal has the remainder is taken advantage of in welding. In welding steel products the work is made the positive terminal, while in welding malleable iron, aluminum, manganese steel, and stellite to steel, the work is made the negative terminal to prevent overheating.

Three very important points were emphasized and are as follows:

(1) Equal reinforcing of weld: In welding plates it is much better to trim the plates on each side so as to form an X rather than on one side to form a V. With the same angles in both cases the X will require only about one-half the welding rod and will make a stronger weld because it will not distort the neutral axis of the piece.

(2) The minimum amount of metal should be filled in so that when the molten metal contracts it will have the minimum strain and warping.

(3) Compensation for contraction: Strains are largely eliminated in the welding of a seam by first laying out the work in equal sections and welding the first section to the right from the zero line, then starting on the second division line and welding to the left, then starting on the third section division line, and so on, always working to the left. Peening will also eliminate strain where work cannot be pre-heated. Welding on a diagonal to the line of service stress will produce a higher strength weld.

If cast iron and malleable cast iron parts are to be welded and still be machinable, the work should be preheated or else annealed afterwards to eliminate the white iron areas. When cast iron work cannot be pre-heated, it is best to drill in along the sides of the V-notch and weld around steel studs previously tapped in and then proceed in a normal manner.

Bronze and monel metal rods work very well on cast iron and malleable iron, but the weld is not as strong in tension. Advantages seem to be with covered welding rods for most purposes on account of a more quiet arc which will also carry somewhat greater amperages.

At the close of the meeting Mr. Malm was given a rising vote of thanks.

R. L. Dowdell.

The North West chapter of the American Society for Steel Treating has just completed its second successful year in conducting a University Extension Course in Metallography and the Heat Treatment of Iron and Steel. This course is being conducted by Dr. O. E. Harder, professor of metallography, University of Minnesota, under the auspices of the chapter. This course has been divided into 16 lessons and laboratory periods, meeting at 7:30 P. M. About one hour has been devoted to the lecture period, followed by laboratory practice. The schedule for the year just completed is as follows:

LESSON 1 INTRODUCTION—Outline of the development of metallography and heat treatment and their importance in modern industry.

LESSON 2 PYROMETRY—Principles of important types of pyrometers and the methods used in their standardization.
Laboratory—Standardization of thermocouple.

LESSON 3 TYPES OF ALLOY SYSTEMS.
Laboratory—Thermal analysis of a typical alloy and casting of specimens for examination.

LESSON 4 LECTURE ON SELECTION AND PREPARATION OF SPECIMENS FOR MICROSCOPIC EXAMINATION.
Laboratory—Polishing, etching and examining specimens of metals and alloys.

LESSON 5 LECTURE ON METALLURGICAL MICROSCOPES AND THE PREPARATION OF PHOTOMICROGRAPHS AND PHOTOMACROGRAPHS.
Laboratory—Microscopic examination of alloys and taking photomicrographs.

LESSON 6 LECTURE ON IRON-CARBON CONSTITUTION DIAGRAM.
Laboratory—Printing photomicrographs.

LESSON 7 LECTURE ON CRITICAL POINTS OF STEELS, THEIR DETERMINATION BY THERMAL ANALYSIS AND THEIR APPLICATION TO HEAT TREATING.
Laboratory—Thermal analysis of samples of steels.

LESSON 8 NORMALIZING AND ANNEALING OF STEEL.
Laboratory—Microscopic examination of annealed steels.

LESSON 9 HARDENING OF STEEL.
Laboratory—Hardening samples of steels.

LESSON 10 TEMPERING AND TOUGHENING OF STEELS.
Laboratory—Tempering or drawing of hardened steels.

LESSON 11 CLASSIFICATIONS OF CARBON STEELS AND DISCUSSION OF THEIR USES.
Laboratory—Identification of steels by means of the spark tests and by appearance of microstructure.

LESSON 12 CARBURIZING OF STEELS.
Laboratory—Microscopic examination of carburized steels.

LESSON 13 HEAT TREATMENT OF CARBURIZED STEELS.
Laboratory—Heat treatment of carburized specimens and examination of fractures.

LESSON 14 — CAST IRON AND ITS HEAT TREATMENT.

Laboratory—Examination of cast iron as cast and as heat treated.

LESSON 15 — STEEL CASTINGS AND THEIR HEAT TREATMENT.

Laboratory—Heat treating steel castings, examination of structures before and after heat treating.

LESSON 16 — HIGH SPEED STEEL AND ITS HEAT TREATMENT.

Laboratory—Inspection tests of high speed steel; microscopic examination of annealed, hardened and drawn specimens.

PHILADELPHIA CHAPTER

The Philadelphia chapter had looked forward to hearing P. A. E. Armstrong of the Ludlum Steel Co. talk on Rustless Iron, at its meeting of April 24, 1925, but illness prevented him from coming. So our good friend T. Holland Nelson took over the job and made a great success of it. He is naturally a good talker on almost any subject but give him something that he knows so well like Stainless Steel and he is hard to beat. He described the different types—the high carbon low silicon, the low carbon-high silicon and the applications of each. He stressed the necessity of caution in recommending Stainless in order to be sure the work at hand was suited to the steel. This is important as so often with a new type of steel, setbacks are encountered because it is used in places for which it was never intended. It was brought out that a wide range of physicals could be obtained but that we should not and cannot expect to get high tensiles and elastics combined with the highest resistance to corrosion. Taken all in all, Mr. Nelson gave us one of the best papers we have had this year because it combined technical accuracy with practical facts clearly presented. An exceptionally active discussion followed.

Continuing the practice of having two papers on an evening we listened to J. M. Watson metallurgist Hupp Motor Co., Detroit, tell about the methods of heat treating alloy steel parts of automobiles. He told of the development from heavy straight carbon parts to lighter and stronger alloy steel parts which of necessity had to be heat treated. After his preliminary talk he showed motion pictures descriptive of these operations. These pictures were taken by the Bureau of Mines cooperating with the Hupp Motor Co.

A. L. Collins, chairman of the membership committee, had the unpleasant job of notifying the chapter that if they did not get busy and provide some new members, the chapter would wind up the year with a deficit. The pervading gloom caused by this plea was pierced by "Bill" Eisenman, our genial and efficient National Secretary, who honored us by his unexpected presence. Bill always has a way of making you think your troubles are not as bad as they might be. And at that we guess he is right.

G. P. Bible, chairman of the nominating committee, presented a list of nominations for next year's officers. This is being written before the results are known so that the new officer's names will have to be published later.

The class in heat treating and metallography, at Mr. Wiedemann's invitation, visited the plant of the Wiedemann Machine Co., 1815 Sedgley Ave., on Monday evening, May 4th, to see various methods of heat treating carried out in a practical way. In spite of a rainy night more than 50 students attended. Mr. Wiedemann demonstrated the operations of hardening and tempering tool steels, in gas furnaces, and oil baths, pack hardening, cyaniding, and the hardening of high speed cutters in salt baths. Methods of quenching thin strips, such as flat springs or knife blades, without warping, were illustrated.

After the demonstration during which nearly two hours passed very quickly, Mr. Wiedemann treated his guests to a hearty "Dutch Lunch" in his machine shop, and this was followed by a lively round-table discussion of practical hardening problems. The keynote was the application of intelligence, care and common sense in the practice of the tool hardener's art. The evening was an ideal combination of pleasure and study and will leave an indelible impression in the minds of all who were fortunate enough to be there.

The last chapter meeting for the year was held on Friday evening, May 22nd. This was a week earlier than usual due to the Spring Sectional Meeting and Memorial Day. It was thought wise to devote this last evening of the year to a thorough discussion of problems. Many of the members had been participating in discussions all year and now they had a chance to go the limit, and it was a good thing because it brought out of those present considerable thought and expression that had evidently been lying dormant for some time.

Arthur L. Collins.

PITTSBURGH CHAPTER

The Pittsburgh chapter held its May meeting in the Assembly Room of the Fort Pitt Hotel on the evening of the 5th.

Through the courtesy of the Westinghouse Electric and Mfg. Co., three motion pictures were shown; the first showed the rolling of steel with electrical power instead of steam; the second illustrated the progress and assemblage of an order for the company's product from raw material to its shipment; and the third compared former household methods with those of today when a great variety of electrical appliances are in general use in the home.

After the pictures, the annual chapter election was held and the following officers and directors were unanimously elected:

President:

O. B. McMillen, Pittsburgh Rolls Corp.

Vice-President:

W. J. Priestly, Electro Metallurgical Sales Corp.

Secretary and Treasurer:

H. L. Walker, Jones & Laughlin Steel Corp.

Directors:

W. B. Crowe, Carnegie Steel Co.

J. P. Gill, Vanadium Alloys Steel Co.

S. L. Goodale, University of Pittsburgh.

C. M. Johnson, Crucible Steel Co. of America.
W. I. McInerney, Pittsburgh Crucible Steel Co.
W. J. Merten, Westinghouse Electric and Mfg. Co.
W. H. Phillips, R. D. Nuttall Co.
Duray Smith, Union Spring and Mfg. Co.

The new officers immediately assumed their duties and, after a short address, President McMillen introduced the speaker of the evening, E. C. Smith, metallurgist of the Central Steel Co., Massillon, Ohio. Mr. Smith chose as his subject, "Some Factors Concerning the Selection of Alloy Steel." And in enumerating these factors, he discussed the properties and limitations of steels containing chromium, nickel, vanadium and molybdenum in various amounts and combinations. An important factor, which is often overlooked when considering the selection of the proper alloy steel to use, is whether the selected steel will give the best results consistently when subjected to the available facilities for fabrication and heat treatment. The question as to the best type of heat treatment equipment for gear hardening was taken up at some length.

That Mr. Smith had selected a most interesting and live subject was fully demonstrated by the unusually large attendance and the great number of members who participated in the lengthy discussion which followed the paper.

H. A. Neeb, Jr.

RHODE ISLAND CHAPTER

No report received

ROCHESTER CHAPTER

No report received

ROCKFORD CHAPTER

The April meeting was the big meeting of the year for the Rockford chapter, the presence of two national officers—W. S. Bidle, national president and W. H. Eisenman, national secretary, being the attraction. Before an audience crowding the Venetian room of the Nelson Hotel to the doors, Mr. Bidle spoke on "Points of Importance in Heat Treating," and Mr. Eisenman spoke on "Our Society."

Since both speeches have been reported on in detail by other chapters thre is no need to go over them again. Suffice to say that they were received with keen interest, especially by the many officials of local and out of town industries present.

The May meeting was somewhat of an innovation inasmuch as we had with us ladies—wives and friends of the members and their guests.

J. M. Watson of the Hupp Motor Car Corporation was the speaker, who illustrated his speech with two reels of motion pictures on the heat treatment of automobile parts.

The attendance was even larger than at the April meeting which, of course, was due to the presence of the ladies, who numbered about one-third of

the total. This, however, did not distract in any way from a very interesting discussion following Mr. Watson's paper. There was one opinion regarding the film, namely—that it was worthy of highest praise for its clearness and the same applied to the accompanying lecture of Mr. Watson, who endeared himself to the ladies by making everything plain and easily understandable.

The Nelson Hotel, which is justly famous for the excellence of its food, did itself particularly proud on this occasion. Everybody was well satisfied.

The election of officers for the new year took place at this meeting and are as follows: chairman, Swan Hillman, National Lock Company; vice-chairman, John A. Nelson, Barber-Colman Company; secretary-treasurer, O. T. Muehlemeyer, 700 Race Street; members of executive committee, Charles Cotta, Cotta Gear Company; G. W. Aldeen, National Lock Company; J. B. Frederick, Whitney Metal Tool Company; M. T. Lundstrom, Sprengler-Loomis Manufacturing Company; A. K. Anderson, J. L. Clark Manufacturing Company; and Richard Johnson, Sprengler-Loomis Manufacturing Company.

The Rockford chapter has never been very active during the summer months. Whether or not any deviation from this fixed policy will be made is to be decided upon at a directors' meeting in the very near future.

J. B. Frederick.

SCHENECTADY CHAPTER

At the annual meeting of the chapter held on May 19, 1925, in the Laboratory Building of the American Locomotive Company, the following were elected officers for the coming year: W. E. Ruder, metallurgist, General Electric Company, chairman; C. K. Getchell, engineer in charge of standard practice, American Locomotive Company, vice-chairman; William Hodges, testing laboratory, General Electric Company, secretary-treasurer. G. H. Wright, metallurgist, General Electric Company, chairman of papers and program committee. Members of executive committee: B. H. Magill, A. C. Mengel and James Taylor, all of American Locomotive Company.

James Taylor.

SOUTH BEND CHAPTER

No report received

SPRINGFIELD CHAPTER

Meeting: May 19, Chamber of Commerce Rooms.

Subject: "Micro-constituents of Steel,"—V. O. Homerberg, instructor in metallurgy, Massachusetts Institute of Technology.

Meeting to be reported in the next issue of TRANSACTIONS.

ST. LOUIS CHAPTER

No report received

SYRACUSE CHAPTER

Meeting: May 18, Uhrig's Restaurant.

Subject: Election of Officers.

Meeting to be reported in the next issue of TRANSACTIONS.

TORONTO CHAPTER

No report received

TRI CITY CHAPTER

Meeting: May 26, University Club.

Subject: "Heat Resisting Alloys and Carburizing Containers,"—H. H. Harris, president of the General Alloys Company.

Meeting to be reported in the next issue of TRANSACTIONS.

WASHINGTON CHAPTER

On April 24, Mr. Deppeler, chief engineer of the Thermit Department of the Metal and Thermit Corp., entertained the members of the Washington chapter with an illustrated talk that was of extereme interest. The first portion of his lecture was devoted to a consideration of the welding of pipe. The method was illustrated by slides showing the permanent metal molds used in the operation, the specially-designed facing machine for use in the field and the method of making welds. An experimental weld was made by the speaker in order to demonstrate the ease and rapidity with which the work can be carried out. It is interesting to note that the metal produced by the thermit reaction in this particular application does not form a part of the weld, but, along with the aluminum oxide from the thermit reaction, serves merely to heat the pipe ends to the welding temperature. The pipes are then butt-welded by forcing them together by screwing up the mold clamps. The aluminum oxide slag which has formed enters the mold first and protects it as well as the pipe from the action of the superheated metal.

Slides were then used illustrating various types of repair work that are carried on by the thermit process. Steamship repairs form the bulk of the work that is undertaken by this method, although the greatest actual number of welds are of broken crankshafts from both marine and other sources. An interesting feature is the frequently-practiced operation of cutting out an entire defective section of a complicated casting, making a forged section of the same dimensions and welding this in place at both ends. Cast iron is also welded by the process, but the welds have not been secured in a uniformly gray form and consequently this particular application is at present somewhat limited.

In welding broken parts of assembled mechanisms, space considerations frequently present great obstacles, and in this connection it was very interesting to watch, by motion pictures, the progress of the welding of the stern frame of the Army transport "Great Northern." Another motion picture displayed the methods used in welding of grooved rails and T-rails. The assembly, along-side of an existing system, of a street car rail close to one-half mile in length and its insertion by "snaking" into position by hand labor afforded a convincing illustration of the ductility of the welds made by the thermit process.

Mr. Deppeler also considered in detail the physical and metallographic properties of the welds, showing the character and extent of the zone of fusion in various welded units. The talk ended with a discussion of the carbon-free

metal and alloys produced by the thermit process, their chemical composition and their sphere of application.

Jerome Strauss.

WORCESTER CHAPTER

A meeting of Worcester chapter was held May 6 in the Electrical Engineering Building of Worcester Polytechnic Institute. Supper was served at 6:30 p. m., and at 8 o'clock the chapter was addressed by Jerome R. George, vice-president of Morgan Construction Co. Mr. George's subject was, "A Unique Rolling Mill," his talk being illustrated by motion pictures and slides.

Previous to the war, Mr. George said, the main steel problems were tonnage and cost. The automobile manufacturers bought a great deal of their steel across the water, and when the war shut off this supply there was a mad rush to secure the domestic product that was available.

Since the war, the American steel industry has striven for quality.

A point brought out by Mr. George was the reduction in manual labor in the steel industry. This was very noticeable in the motion pictures shown from which it would almost seem that the entire rolling operation was automatic. Mr. George said that during the last 25 or 30 years the tonnage per man had increased about eight times.

The motion pictures showed a continuous type of Morgan rolling mill located in the South Chicago works of the Interstate Iron and Steel Co., formerly the Grand Crossing Tack Co.

This mill was originally designed for a production of 200 tons per day, provision being made for expansion to 1500 tons.

Today, Mr. George said, his company was making a mill with a capacity of 175 tons per hour.

The continuous type of rolling mill was stated to be the only type that would permit of finishing a piece of steel with both ends at the same temperature. This means that the billets will be uniform in temper. The importance of controlling closely the temperature at which the steel leaves the rolls, as well as the rate of cooling after the steel leaves the rolls, was stressed by Mr. George.

The mill illustrated, which, by the way, was constructed 18 years ago, contained a number of novel features which have since been adopted as standard practice, a most interesting detail being the 360 degree repeater for securing the final passes through the rolls.

Another interesting piece of mechanism shown in the motion pictures was the Edwards Flying Shear.

This shear travels with the steel as it cuts it. Originally it was designed to cut the billets at a speed of 300 feet per minute which was increased to 600 feet and then a thousand feet per minute. At present such a shear is in operation cutting off 2500 tons of billets per day.

The meeting was very well attended, there being between sixty and seventy present, while forty were the attendance at the supper.

R. J. Phelon.

Items of Interest

ON May 14, 1925, the C. L. Best Tractor Co. and The Holt Manufacturing Co. ceased operations under their respective names, and from that date their plants and businesses will be operated by the Caterpillar Tractor Co. On May 14 all assets of the C. L. Best Tractor Co. and The Holt Manufacturing Co. were transferred to the Caterpillar Tractor Co., which will assume all liabilities of the two companies.

Best and Holt tractors and parts for all models of same will continue to be manufactured by the Caterpillar Tractor Co., at its plants located at San Leandro and Stockton, California, and at Peoria, Illinois.

The Caterpillar Tractor Co. was incorporated under the California laws, April 15, 1925. The stockholders of the Best and Holt Companies have ratified the action of their respective boards of directors in exchanging the assets of the two companies for the stock of the Caterpillar Tractor Co., and the confirmation of the consolidation were effected on May 14, 1925.

The Caterpillar Tractor Co. will be guided by the following officers and directors: C. L. Best, chairman of the board; R. C. Force, president; B. C. Heacock, vice-president and secretary; M. M. Baker, vice-president; P. E. Holt, vice-president; O. L. Starr, general factory manager; H. H. Fair; A. L. Chickering; J. A. McGregor.

C. L. Best was formerly president of the C. L. Best Tractor Co. R. C. Force has been for many years vice-president and general manager of the C. L. Best Tractor Co. B. C. Heacock was an executive of the C. L. Best Tractor Co., and M. M. Baker was formerly vice-president in charge of the Peoria plant of the Holt Manufacturing Co. P. E. Holt was engineering vice-president of the Holt Manufacturing Co. O. L. Starr was factory manager of the C. L. Best Tractor Co. H. H. Fair was of the executive committee of the C. L. Best Tractor Co., is vice-president of Peirce, Fair & Co. and was largely instrumental in the consolidation of the companies. A. L. Chickering is a prominent San Francisco attorney, of the firm Chickering and Gregory. J. A. McGregor was formerly president of the Union Iron Works and was prominent in San Francisco civic affairs.

The University of Michigan, Ann Arbor, Michigan, has just published their University Bulletin, describing their course in chemical engineering and graduate courses in general chemical engineering, metallurgical engineering, gas engineering and the organic chemical industries. This bulletin may be obtained upon request by addressing Alfred H. White, professor of chemical engineering.

E. J. Maxwell, formerly with the Walworth Mfg. Co., Kewanee, Ill., is now employed with the Stanley Flagg Co., Inc., at Pottstown, Pa.

(*Continued on Page 34 Adv. Sec.*)

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice

In addressing answers to advertisements on these pages, a stamped envelope containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave., Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

HEAT TREATING FOREMAN desires position. Thoroughly experienced with executive experience and complete knowledge of all steels. Address 6-1.

HARDENER FOREMAN with a thorough knowledge of the heat treatment of high speed, carbon and alloy steels and carburizing, is open for engagement. Has held executive positions for the last 12 years. Age 38. Married. Address 5-5.

EXPERIENCED HARDENER desires position. Has had full supervision over hardening, sand blasting, carburizing, Hump method of hardening gears, cyanide hardening, lead pot, salt pot, barium and salt petre and oil drawing work. Also has had two years' experience at pyrometer checking and installing. Semi-muffle furnace and production hardening of all kinds. Address 6-10.

GRADUATE MECHANICAL ENGINEER desires position as assistant superintendent or engineer of tests. Age 38. Fourteen years' experience in production, heat treatment, inspection and fabrication of steels. Have successfully handled carbon, alloy and high speed bar steels and served as assistant metallurgist, metallographer and heat treater. Address 6-15.

POSITIONS OPEN

SALES ENGINEER: Familiar with selling engineering specialties or instruments. Must have had several years' selling experience. Not over 35 years old. Interesting proposition for man with this experience. College graduate preferred, although not necessary. Location in east preferred. Address 5-10.

EXPERIENCED HARDENER with a thorough knowledge of the heat treatment of high speed, carbon, alloy steels and carbonizing. Position assistant to foreman and applicant should be capable of taking charge. In answer, detail experience, age, married or single and state salary expected. Address 6-20.

FOR SALE

FOR SALE: 50-Ton Tinius Olsen Belt Driven Testing Machine with full equipment for steel test bars. Practically new. Price very reasonable. Address Bay State Machinery Co., 54 Old Colony Ave., South Boston, Mass.

FOR SALE—Three SHORE SCLEROSCOPES. With stands; in very good condition. Price $115.00 each. Address 6-5.

HEAT TREATING EQUIPMENT FOR SALE: Two No. 150 Bellevue Furnaces. Brand new. Never used. Low price for immediate sale. Address Curtiss Aeroplane & Motor Co., Inc., Buffalo, N. Y.

With increasing attention being given to the use of powdered coal as an industrial fuel, interest attaches to a bulletin just issued by the Department of the Interior, which gives the results of powdered coal tests made by Bureau of Mines engineers at the Lakeside station, Milwaukee, the largest central power station in the world that burns powdered coal exclusively. The object of the tests was to determine the thermal efficiencies and capacities obtainable by burning powdered coal under large central-station boilers, and the possibility of operating such boilers continuously at high efficiency and capacity without destructive effect on the furnaces and without difficulties in refuse removal.

In any system for burning pulverized coal the furnace is the most important part because, to justify the cost of pulverizing, the powdered coal must be burned with higher efficiency than coal fired with mechanical stokers. In other words, it is the furnace that by giving higher thermal efficiency must pay for the installation, maintenance, and operation of the pulverizing equipment. No matter how simple the apparatus for the preparation of pulverized coal may be, or how simple the pulverizing process, unless the furnace is so designed that it can be operated continuously with high thermal efficiency, the whole system is a failure.

For high thermal efficiency the coal must be burned almost completely with low excess air. But low excess air and complete combustion give high furnace temperature, which in turn causes erosion of the furnace lining and fusion of the ash; and removal of the fused ash is difficult. The necessity of complete combustion with low excess air thus brings with it two important problems in the design of a furnace for burning powdered coal: Prevention of erosion of the furnace lining; and easy removal of refuse from the furnace.

For the purpose of solving these problems, the boiler tested was equipped with a furnace having hollow walls, through which about 60 per cent of the air needed for combustion passed before it entered the furnace. By passing through the hollow walls, the air cooled the furnace lining and prevented excessive erosion.

Powdered bituminous coal will explode in suspension in the air; that is, when it is in the form of a dust cloud. Under this condition the dust must be ignited by a flame or static sparks and the intensity of explosion depends upon the proportion of dust and air. When lying in a bin coal dust will not explode if a burning stick is thrust into it. Therefore, to prevent an explosion, dust clouds and flames must be kept apart.

Plants using powdered coal can be kept free from coal-dust clouds and be just as clean or even cleaner than stoker-fired plants. There is as little reason to allow coal dust to leak out of coal conveyors or other transports as there is to allow gas to leak out of gas lines. Powdered coal has a reputation for dirt because some of the first powdered-coal installations were put in and operated rather carelessly and coal dust was allowed to accumulate promiscuously. Recent powdered-coal installations are much cleaner and before long a powdered-coal plant will be considered as safe as a stoker plant.

Bulletin 237, by Henry Kreisinger, John Blizard, C. E. Augustine, and B. J. Cross, may be obtained from the Department of the Interior, Bureau of Mines, Washington, D. C.

S. M. Co. Brinell Machine

This machine applies a pressure of 3,000 Kilos to a 10 mm. ball and gives results in Brinell numerals, the international standard for indicating hardness of metals.

The Pressure is applied quickly and evenly, and a patented feature prevents the leakage of the hydraulic fluid.

Pieces from $\frac{3}{16}$ inch to 12 inches may be accommodated. The anvil is adjustable to irregular shaped pieces.

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Piston Ring Co.
Pittsburgh Testing Laboratory
Pollak Steel Co.
Premier Motor Corp.
Railway Steel Spring Co.
Standard Foundry Co.
Standard Steel Car Co.
Standard Steel Spring Co.
Studebaker Corp.
Underwriters' Laboratories
Union Switch & Signal Co.
Vanadium Alloys Steel Co.
Westinghouse Electric & Mfg. Co.

And Many Others

Send for descriptive bulletin 103

SCIENTIFIC MATERIALS COMPANY

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The following installations have recently been made by the American Metallurgical Corporation of Boston: 3-20 K. W. pot type units for lead hardening at the Pratt & Whitney Co., Hartford; 1-20 K. W. cyanide pot unit at the Arrow Electric Co., Hartford; 1-20 K. W. cyanide pot unit at the Moore Drop Forging Co., Springfield, Mass.; electrically heated paraffine spraying outfit at the Seamless Container Co., Hartford; 15 K. W. tool furnace at the Hemming-Walsh Mfg. Co., New Haven, Conn.; 22 K. W. box type electric furnace at O. K. Tool Co., Shelton, Conn.; 27 K. W. box type electric furnace at the Norton Company, Worcester, Mass.; 68 K. W. electric air heater for the F. N. Burt Co., Buffalo; 15 K. W. electric tool furnace at the Union Hardware Co., Torrington, Conn., and 15 K. W. electric tool furnace at the Buchanan & Bolt Wire Co., Holyoke, Mass.

The Bell & Gossett Company of Chicago has been appointed Illinois representative of the American Metallurgical Corporation, while the Case Hardening Service Company of Cleveland has been made Ohio representative. A. C. Wright of Springfield, Mass., has been appointed consulting engineer and Western New England representative. Stanley N. Juthe, formerly sales manager, has been elected vice-president in charge of production.

Gordon A. Webb has opened an office at 733 Majestic Building, Detroit, acting as district manager for Rodman Chemical Co., Verona, Pa., handling carburizing compounds, quenching and tempering oils, and luting material as well as for the F. J. Ryan & Co., Philadelphia, who handle all temperature furnace cements, known as Thermoloth and Firebond, manufactured by the Harbison-Walker Refractories Company of Pittsburgh. Mr. Webb, who is affiliated with the Detroit chapter, has been a member of the American Society for Steel Treating for a number of years, joining at the time the Buffalo chapter was organized.

Metallurgy of Aluminium and Aluminium Alloys, by Robert J. Anderson, has recently been published by Henry Carey Baird & Co., Inc., 2 West 45th St., New York. This book contains 944 pages, 295 illustrations, 6¼x9¼ inches and cloth bound. Price $10.00.

This volume is a thorough and comprehensive presentation of the metallurgy of aluminium and aluminium alloys, covering the subject from the mining of bauxite to the uses and applications of the metal and its alloys.

In the introductory chapter, the history, development and ramifications of the aluminium industry are traced, and statistical data showing the output of the metal in the various producing countries are given. The origin, occurrence, and distribution of aluminium ores and methods of mining are taken up in an early chapter, while the production of aluminium itself by modern electrolytic methods is also discussed in another chapter.

The chapter on physical and chemical properties of the metal and its alloys is full of data that have hitherto been widely scattered in the literature. In the chapter dealing with corrosion, the behavior of aluminium and aluminium alloys when in contact with the various corroding agents is dis-

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cussed, and methods for protection against corrosion are given. The uses and applications of the metal and its alloys are treated in detail.

Considerable attention is given to the preparation of alloys for casting and working, and the most approved methods for preparing the principal alloys are described. Melting practice for aluminium and its light alloys is discussed on the basis of the author's extensive investigations in the U. S. Bureau of Mines, and the best methods of melting, together with descriptions of the principal types of furnaces, are given detailed treatment. In one chapter, the production of secondary aluminium alloys from aluminiferous scrap is taken up, and the information given will be found of interest to the secondary metal industry.

The founding of aluminium alloys, which has assumed so much importance in the automotive industry as well as in the general engineering trades, is discussed quite fully, and the information given will be of great value to foundrymen in the successful production of castings. Casting losses and defects in castings are taken up, and the methods of producing castings with a minimum of wasters fully explained. An increasing number of parts is being made by die casting and permanent-mold casting, and the production of castings by these methods is given detailed consideration. The mechanical treatment of aluminium alloys for the production of sheet, forgings, bars and other finished and semi-finished manufactures is discussed, and this chapter will be found of great value to rolling-mill managers.

Some of the more theoretical aspects of the whole subject are treated in the chapters dealing with the constitution of aluminium-alloy systems and the metallography and heat treatment of aluminium and its alloys. The annealing of cold-rolled aluminium sheet is described, and considerable attention is paid to the heat treatment of some aluminium alloys, particularly duralumin. The latest information on this remarkable aluminium alloy is presented, and methods for its heat treatment are discussed.

The chapters on soldering and welding, and on working, spinning and machining will be of great value to the metal worker.

The author, Robert J. Anderson, is the well-known consulting metallurgical engineer and technical specialist on aluminium, who was formerly in charge of the aluminium investigations of the U. S. Bureau of Mines. He has prepared more than one hundred technical papers on aluminium and aluminium alloys. His experience covers many years in all branches of the industry, and he has brought together the fruits of his extensive experience in this important work.

J. Q. Holmes, formerly with the Remy Electric Company, is now associated with the Davis Boring Tool Company of St. Louis as assistant to the president.

Holcroft & Co., Detroit, announce that after May first, C. H. Martin will be the district representative of the company in Wisconsin and Illinois. The increased volume of business from these two states has made it essen-

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tial, and in order to carry out service to their customers and also their prospects, they find it necessary to place a man permanently in Chicago. Mr. Martin, who was formerly with the Peoples Gas Light and Coke Company, and who was one of their most able men, will be their representative. The sales this year so far are very satisfactory and have exceeded anything in years past. This, perhaps, is due to the revising and rearranging of many of the heat treating plants who are adopting the continuous type furnace.

I. J. Stormer, for many years connected with the J. I. Case Machine Company, died at his home in Racine, on April 20. Mr. Stormer was a member of the A. S. S. T. from its early inception and was a frequent attendant at the Milwaukee and Chicago chapter meetings.

Arthur W. F. Green, who for nine years has been in the production department of the John Illingworth Steel Company, is now in the capacity of sales metallurgist.

The firm of Deeds and Chapin is now known as the W. R. Chapin Company, manufacturers of Cinch steel cement and consulting metallurgists, with offices at Indianapolis, their address being P. O. Box 692.

It has been announced that the Republic Flow Meters Company of Chicago will open a factory branch office in Cleveland, at 617 Engineers Bldg. It will be in charge of L. C. Wilson, formerly of their Pittsburgh office. They find that business has expanded so rapidly in Ohio that it was impossible to give customers and prospects sufficiently personal service from Pittsburgh. Mr. Wilson is an engineer with many years of experience in the power plant field and will be glad to give assistance or information whenever there are problems in the field of fluid measurement or power control.

Maurice Schramm, 17, 16919 Grovewood Ave. N. E., Cleveland, senior at East Technical High School is first prize winner for Ohio in the national essay contest conducted annually by the American Chemical Society. His reward is a gold medal and $20.00 in gold. In addition his essay will compete with others from every state for six scholarships to Yale university. Each scholarship includes tuition fees for $500.00 yearly for four years. Mr. Schramm chose for his subject, the relation of chemistry to the development of a national industry or resource and told the "Story of Coal." He is a junior member of the A. S. S. T.

Benjamin Whitehead, employed with the Columbia Steel Corporation, Pittsburg, Calif., died on May 16th.

G. H. Webb has been appointed Philadelphia sales manager of the Central Steel Company of Massillon, Ohio. He succeeds A. B. Cooper who died suddenly at his home in Philadelphia on Sunday, May 3rd. Mr. Webb has been identified with the Central Steel Company over eleven years and is thoroughly acquainted with their many analyses of Agathon alloy steels.

Transactions of American Society for Steel Treating

Vol. VII June, 1925 No. 6

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Carburizing and Heat Treatment of Carburized Objects—
B. F. Shepherd 774

UMA steels

Central Steel Blooming Mill

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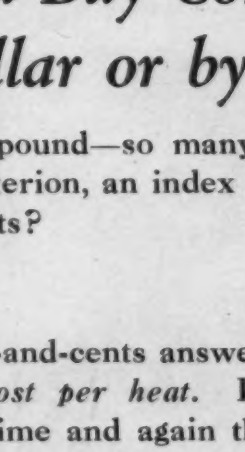

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THE

TRANSACTIONS

OF THE

AMERICAN SOCIETY FOR STEEL TREATING

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RAY T. BAYLESS, *Editor*

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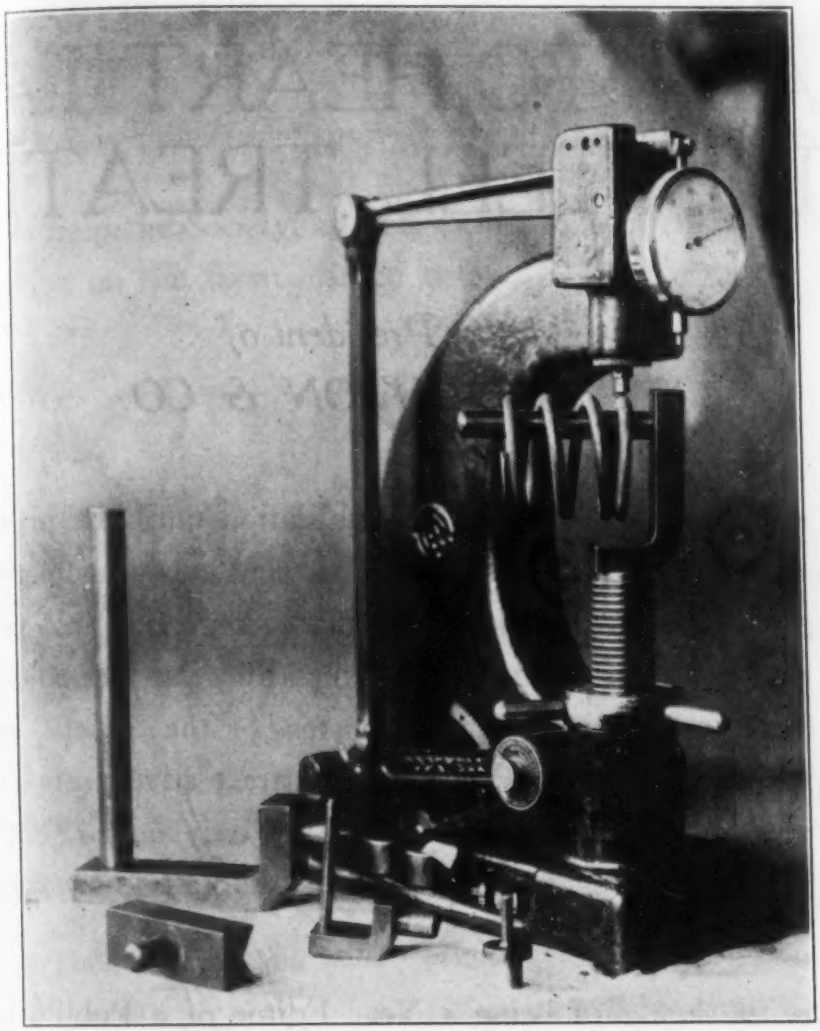

1 2 3 4 5

Rockwelling Springs

Mr. H. P. Troendly has very kindly sent us this photo, showing special anvils made and used by the Wm. D. Gibson Co., Chicago, for testing their product, springs. Anvils 2, 3 and 5 are used to test springs formed and hardened. No. 1 is used for some long, round stock. No. 4 is used to secure tests near to the bends of small flat springs. Hundreds of users of the Rockwell are finding that a few simple, well made and well fitted anvils enable them to make quick, accurate and convenient tests of their product.

WILSON-MAEULEN COMPANY INC

379 Concord Ave. New York

HEART TO HEART TALK WITH STEEL TREATERS

By the President of
E. F. HOUGHTON & CO.

FROM the very inception of this publication until the present time we have given to it every possible aid and encouragement, because it is a step in the right direction. It is to be regretted that representatives of publishers of chemical and metallurgical periodicals, while claiming to be warm friends and supporters of the Society, are knocking this publication, in their attempts to attract advertisers from it to their own publications. Such actions are not only unfair, but they are deceitful, and true friends of the Society should know what to do about it.

I have the honor of being a Near Editor of a Publication called *The HOUGHTON LINE*. The subscription is free to those engaged in industrial enterprises. It is mailed only to individuals upon request. Not necessarily the request of the individual receiving *The LINE*, but some reliable person must make the request in writing, and *The LINE* will not be mailed free to firms, corporations, or other than individuals.

The circulation of *The LINE* is 135,000 in the United States alone. There is also a British edition, a French edition printed in French, and a Japanese edition printed in Japanese.

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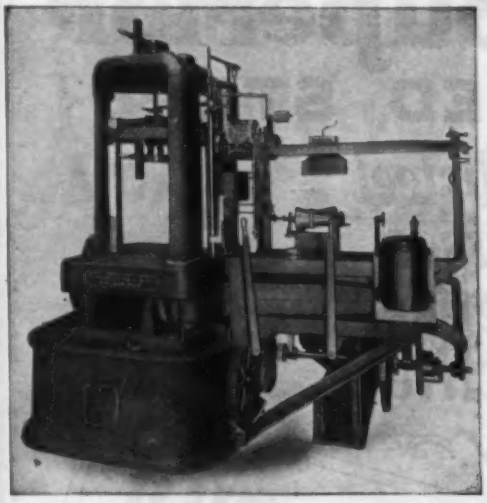

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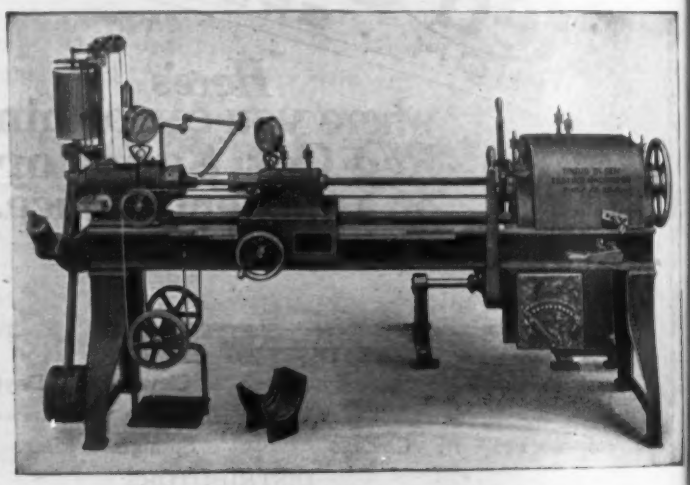

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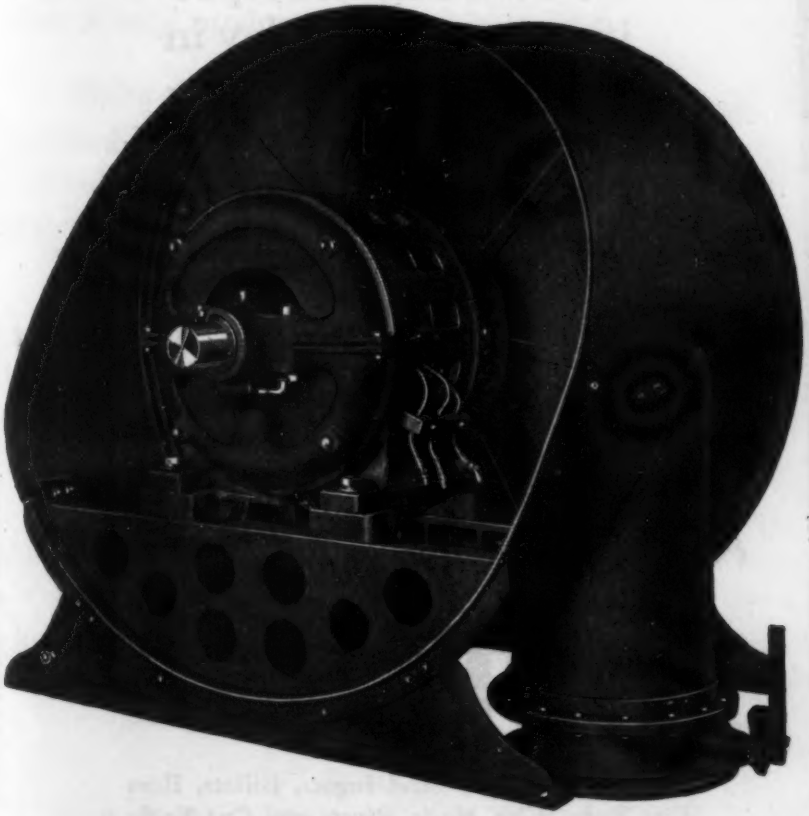

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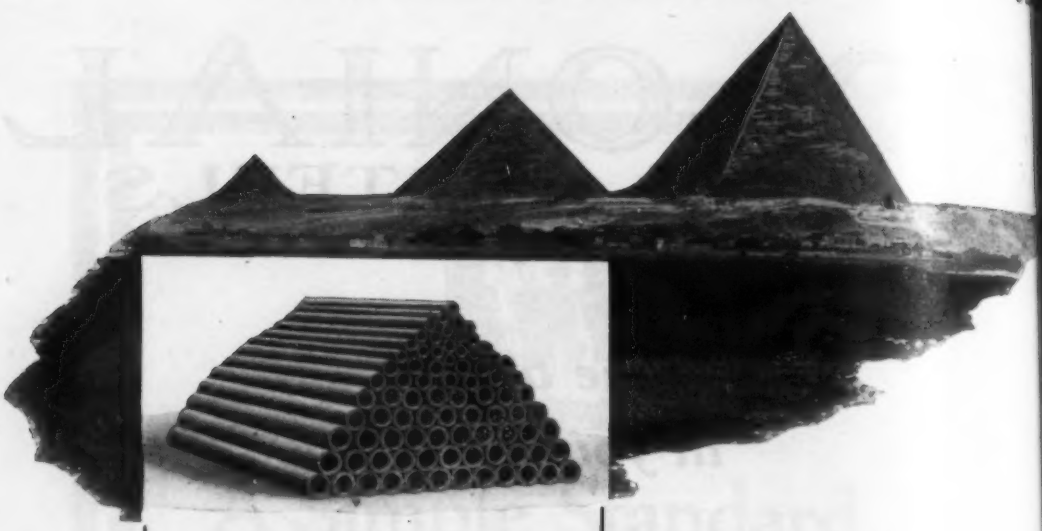

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This booklet discusses proper heat treatment temperatures and operations, explains the most approved practice in steel treating, and describes quenching and cooling equipment that has given the most satisfactory results in hundreds of progressive plants such as Buick Motor Co., Falk Co., Hyatt Bearings Division of General Motors Corp., Packard Motor Co., and Ingersoll-Rand Co.

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Think of the stress of it—on men and on metals! Think of the need for strength —endurance—toughness! For every stressed and moving part—particularly in the bearings—there is need for strength with lightness, elasticity with toughness, and hardness that gives but does not break; in short,—there is a need for Alloy Steels.

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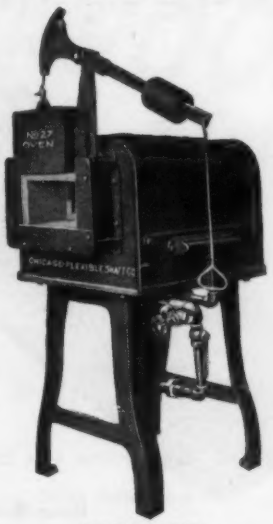

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For gas or oil.
One of many sizes.
A size for your requirements.

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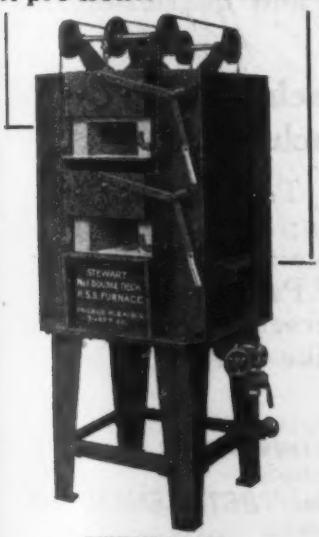

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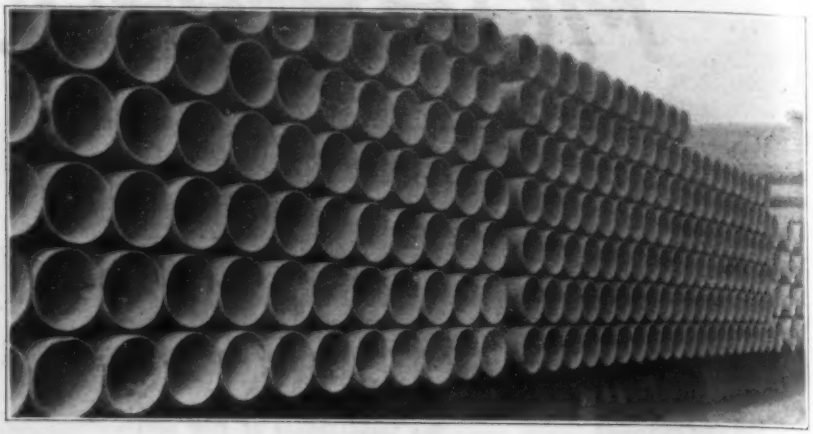
Brown Pyrometers
Most used in the world

Shipped and Stored without Rust



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(1) The medal will be awarded to the author of the paper which shall be judged to be of the highest merit. All papers in order to be considered must be published originally in the TRANSACTIONS of the Society during the twelve months ending August 1st of the year in which the medal is awarded.

(2) The competition for the Henry Marion Howe Medal shall be open to all.

(3) The award shall be made by the Board of Directors.

(4) The award may be withheld at the discretion of the Board of Directors.

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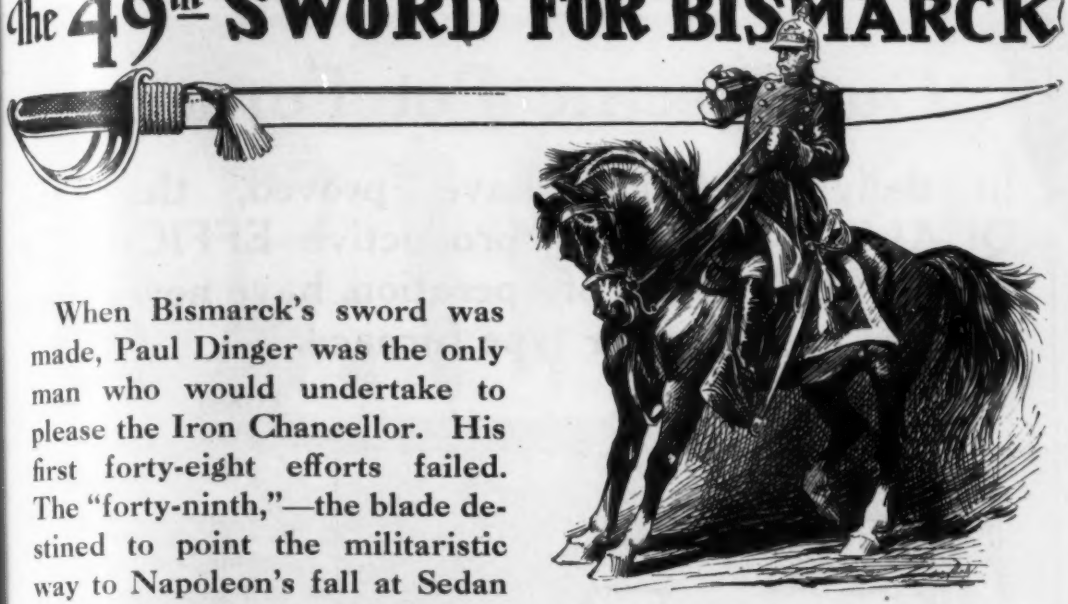

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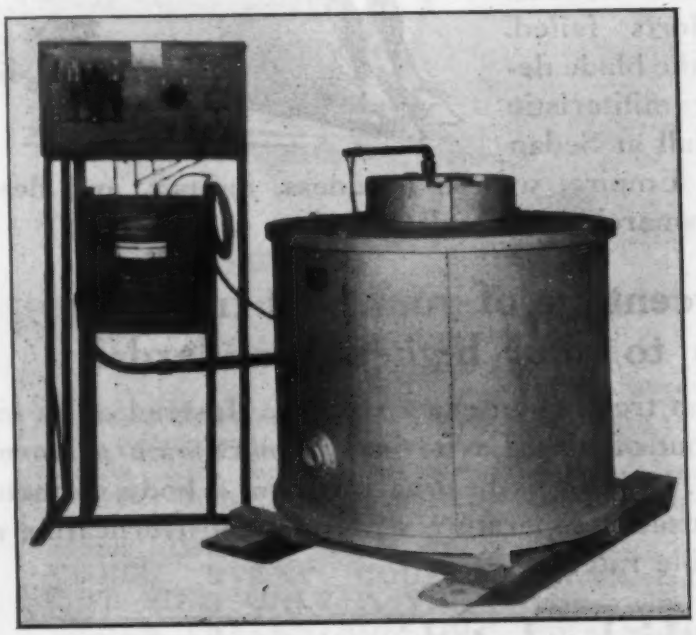

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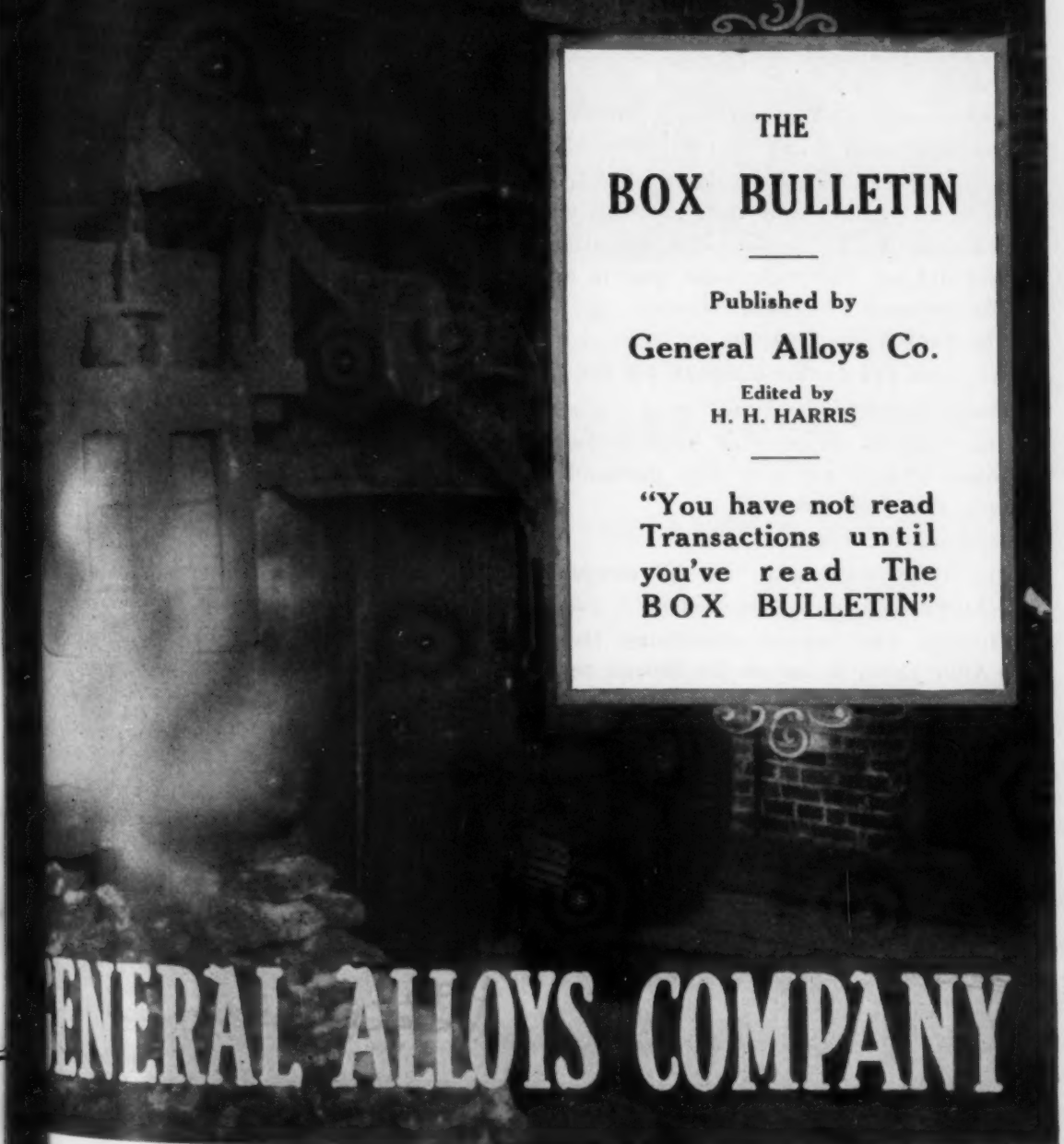

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We refer you to this company for the facts involved.

Dodge Brothers.

The "partial shipment of boxes to Dodge Bros." advertised is part of an order for 12 boxes. There are over two thousand Q-Alloy castings in this plant some of which have run four years.

Studebaker Corpn.

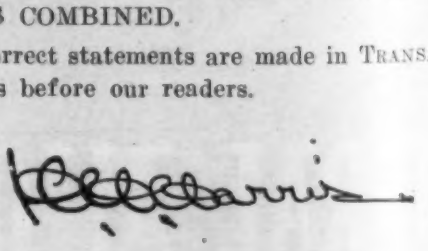
The "partial shipment" to this company is a trial order. There are over eight hundred Q-Alloys castings in this company's plants some of which have run four years.

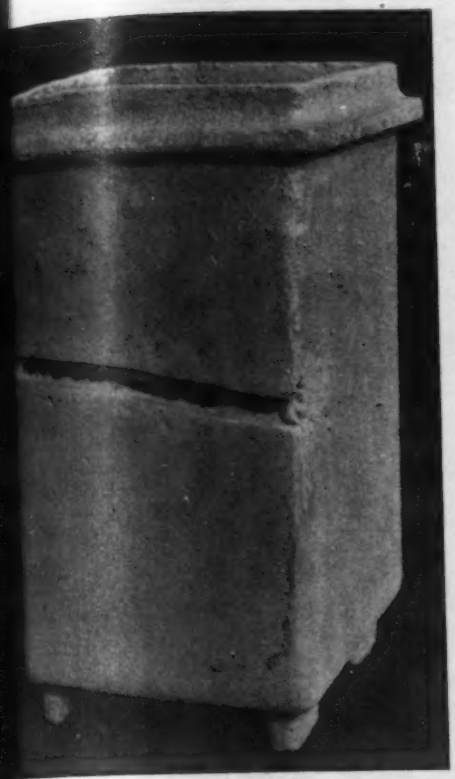
Although the concern advertising these users is located in Detroit, There are Ten Q-Alloy boxes in use in the Detroit territory to one of the low priced Alloy advertised. In no single plant has a low priced alloy ever compared favorably with Q-Alloy Boxes.

While mentioning the Detroit Territory, admittedly the largest Carbonizing Box market in the World, it is opportune to state that:

DURING THE PAST YEAR THERE HAVE BEEN TWICE AS MANY Q-ALLOY CARBONIZING BOXES SOLD IN THE DETROIT TERRITORY AS ALL COMPETITIVE ALLOY CARBONIZING BOXES COMBINED.

We don't care a darn how many foolish or incorrect statements are made in TRANSACTIONS so long as we are permitted to place the facts before our readers.





s Box ran 1,420 hrs. over guaranteed . Then cracked.

Rewelded with Q-Alloy it is given a new lease of life.

WELDING OLD BOXES TO MAKE THEM NEW

e desire to benefit by serving others,—to turn Customers' Satisfaction into next year's iness,—is part of a sound business policy.

is company instructs its Sales Engineers:

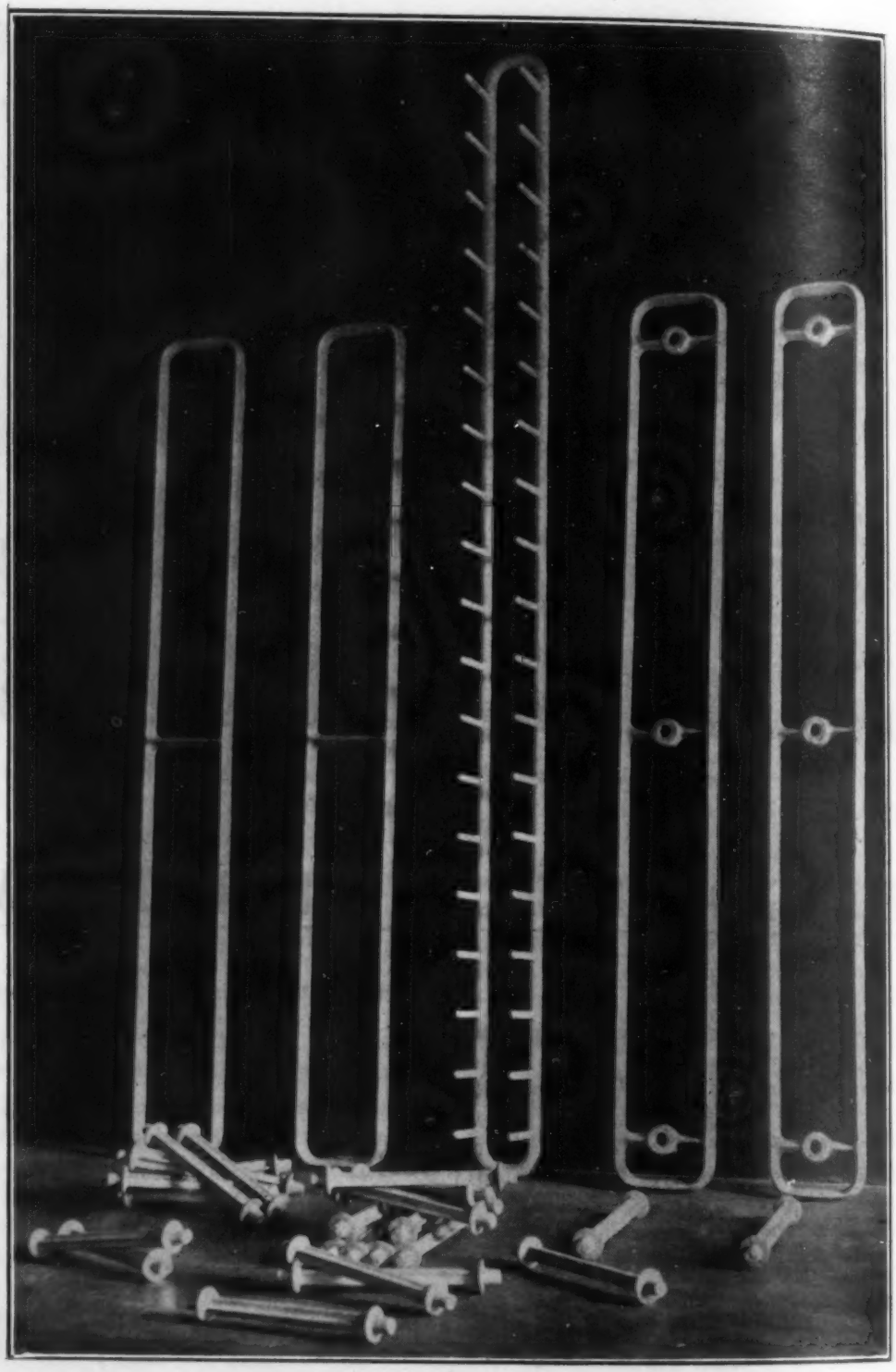
"Sell the Customer the lighest possible boxes, and the least amount of Q-Alloy that will do his job efficiently,—don't sell heavy boxes or 'load up' a customer."

"Our Guarantee is merely 'Insurance' of MINIMUM LIFE, all Q-Alloy boxes should run much longer than the guarantee. Help the user get the utmost life out of his Q-Alloy equipment,—make it double the Guarantee if possible.

part of this Policy, which is merely Good Business, we have developed the Welding Q-Alloy castings to the point that it is now possible to get from 1,000 to 3,000 hours more additional life from many Q-Alloy Boxes, after they are pronounced "Unfit for ther service".

e can supply Welding rods of our standard mixture, and suitable flux to any of our tomers to weld in their own plants.

BOX BULLETIN SUPPLEMENT PAGE IV



"Knife-Edge" Q-Alloy Enamel Burning Racks 4 ft. to 5 ft. 6 in. long, weight 17 to 23 lbs.

At least one Concern supplying the enameling trade can supply light, uniform, non-sc ing burning racks. These Q-Alloy racks are *malleable*, not brittle, and are as far ahe of the "Cheap" alloys supplied the enameling trade as Q-Alloy boxes are ahead of the enti Carbonizing Box field. They are cast in one piece and they will stay that way a long ti

CHARTS

WE have been highly amused by some charts appearing in the advertising section of the last TRANSACTIONS. These charts showed how an Alloy costing 40¢ per lb. cost less on the basis of 7,000 heat hours than higher priced alloys, Q-Alloys, of course, being included, as the chart was all-embracing.

The author of these "Charts" started by comparing low priced Alloys and high grade alloys on the basis of even weights and assuming that the "Cheap" alloy (whose manufacturer, of course, wrote the charts) runs 7,500 heat hours, "proving" that an alloy box at 40¢ per pound which runs 7,500 heat hours is cheaper per heat hour than an alloy box at 85¢ or more per pound that runs only 7,500 heat hours. All of which simply proves that it is as easy to write fairy tales in the form of charts, as in any other form,

FOR,—NO ALLOY CARBONIZING BOX AT 40¢ per lb. AND 3/8" section EVER RAN 7,500 heat hours OR ANYTHING LIKE IT.

Our contention is this:—(If you want facts to prove it write on your letter-head)

A. 50% of the carbonizing boxes of average size manufactured by any "Cheap" Alloy maker to meet Q-Alloy weights in 3/8" section have failed utterly in less than 2,000 hours.

B. 95% of all "Cheap" Alloy boxes weigh from 100% to 150% more than Q-Alloy boxes of the same cubic content. 50% excess weight is a low figure to set as an average.

C. Taking 50% increased weight the 40¢ alloy weighing 50% more would cost the same as a properly designed light weight box at 60¢ lb.

BUT: WITH ANY GIVEN NUMBER OF BOXES, assuming that the charge weighs the same as the box (the charge is usually much lighter), you will increase the total weight of your furnace charge 25% to turn out the same amount of work. In addition you will increase your heating time one to three hours and your fuel bill in proportion, REDUCING YOUR PLANT CAPACITY 25% or more.

CHARTS (Cont'd)

D. EVEN WITH THE 50% INCREASED WEIGHT NOT ONE ALLOY BOX IN FIVE WILL RUN 4,000 hours. A LARGE NUMB WILL CRACK IN LESS THAN 500 hours.

E. THE 40¢ ALLOY BOXES ARE NOT GUARANTEED AT ALL. Y ARE HOLDING THE BAG, AND THE $$$$$ YOU STAND TO LO ON HEAT HOUR COSTS ARE SECONDARY TO WHAT YOU WI LOSE IN PLANT EFFICIENCY.

F. You can get 7,500 hours' life from a steel box if you make it th enough. The same is true of cheap alloy. Make 'em thick enough they'll last a lifetime. But you don't want thick boxes, if you're pay to heat 'em, and are blessed with common sense.

G. You are living in an age where more and more brains are being mi with metals to make one pound do the work of two. The Best steels invariably the cheapest in the long run. Good alloys, like good sh are worth the price.

H. Propaganda of retrogression is detrimental to every sound busin principle and injurious to industry as a whole. The Railroads will ne be run by dollar watches. Neither will any large amount of carboniz in modern plants ever be done in Carbonizing boxes of such low qual that they sell at 40¢ per lb.

MAYBE YOU ARE FROM MISSOURI,—YOU WANT FACTS DON'T WASTE YOUR BOSS'S MONEY EXPERIMENTING WI CHEAP BOXES, BUT SPEND 20¢ FOR POSTAGE AND WRI THE TEN LARGEST MANUFACTURERS IN DETROIT, OR TH TEN LARGEST AUTO BUILDERS AND LEARN THE RESUL OF THEIR TESTS OF THESE CHEAP 40¢, 50¢, 60¢ and 70¢ alloy

KRIT IKLEPOINT.

NO CORRECT ANSWERS RECEIVED TO LAST CROSS WORD PUZZL

WE'LL SAY IT AGAIN, IN LARGE TYPE
AND WE HOPE YOU WILL REALIZE
THE FULL SIGNIFICANCE

THERE WERE MORE Q-ALLOY CARBONIZING BOXES SOLD SINCE JANUARY 1st THAN ANY OTHER ALLOY

WE'LL ADD ANOTHER FACT—THUS

THERE WERE MORE Q-ALLOY CARBONIZING BOXES SOLD SINCE JANUARY 1st THAN ALL "LOW-PRICED" ALLOYS COMBINED

(MEANING ALL ALLOYS FROM 20c TO 70c LB.)

Are we cheating the public, or do American Buyers recognize value? You decide.

Q-ALLOYS

Most Economical and Efficient Materials

For CARBONIZING BOXES
ANNEALING BOXES
CYANIDE AND LEAD POTS
FURNACE PLATES
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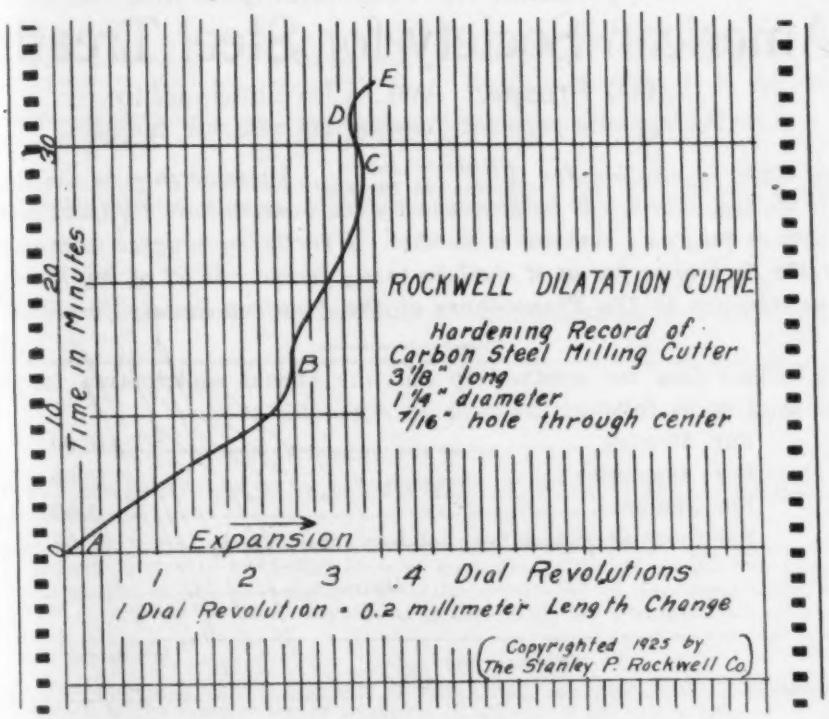

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Dues $10.00 per annum.

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THERE is no other commercial refractory material that has the remarkable heat conductivity of Carbofrax—the Carborundum Refractory.

With Carbofrax hearths in your heat-treating furnaces you are assured of a uniform flow of heat which is reflected in the more uniformly heated ware—in the saving of fuel and increased general efficiency of the furnace.

With a Carbofrax hearth you can bring the furnace up to heat much quicker and you can hold it there.

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They show a decided resistance to abrasion and they will last months as against weeks for fireclay.

Made for all standard furnaces in one piece up to 24 x 15 and 24 x 24 inches—larger hearths in sections.

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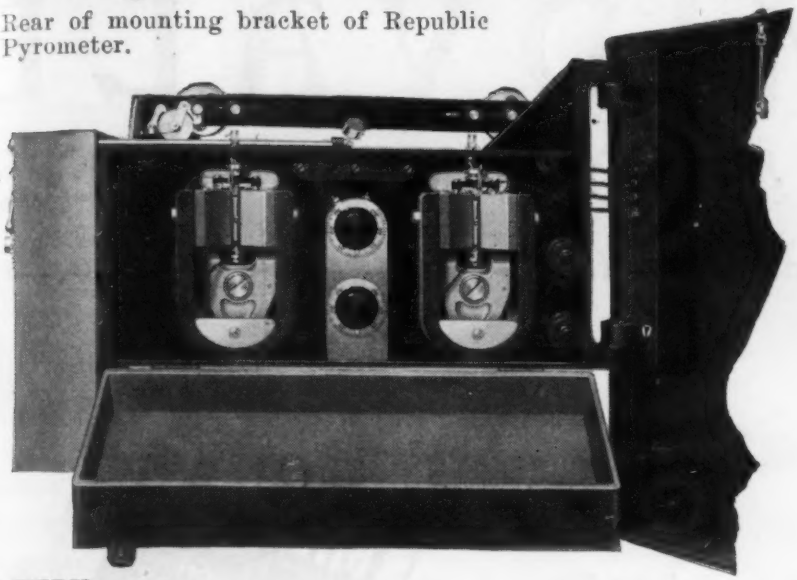
Complete Accessibility

Rear of mounting bracket of Republic Pyrometer.



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Painstaking care in minute details in design.
Every part tooled up before going into production
Careful inspection and highest standards
can low cost for unit of service rendered be built into an instrument from which is secured the maximum in continuous, accurate, performance.

In addition to an unequalled reliability these exclusive features will appeal to practical users of pyrometers.

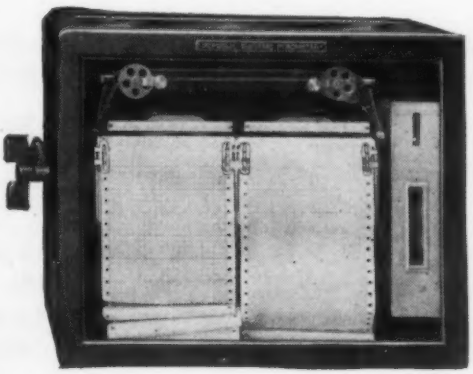
Separate charts—wider than any other duplex enable more accurate reading.

A tear groove permits instantaneous extraction of record without chart waste.

A 50 ohm Rheostat for instantly adjusting for changes made in the external circuit.

Highest resistance pyrometer. The higher the resistance the greater the accuracy.

Republic Catalog Pyr. 30 will be promptly sent at your request.



The Republic Recording Pyrometer

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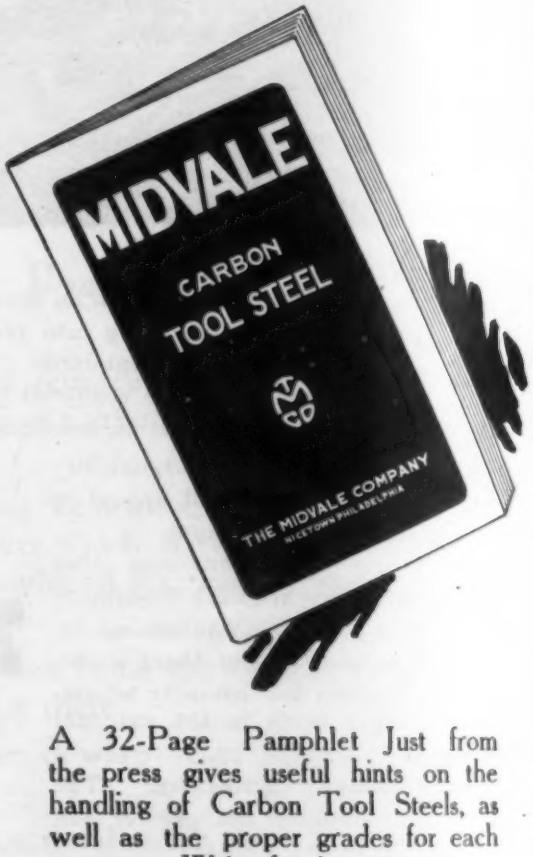
CARBON TOOL STEELS

Made to Sell for a Purpose—Not a Price

Our experience of over 50 years in the manufacture of Steel Specialties guarantees you the Best Tool Steels that can be made.



A 32-Page Pamphlet Just from the press gives useful hints on the handling of Carbon Tool Steels, as well as the proper grades for each purpose. Write for it.

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NICETOWN, PHILADELPHIA

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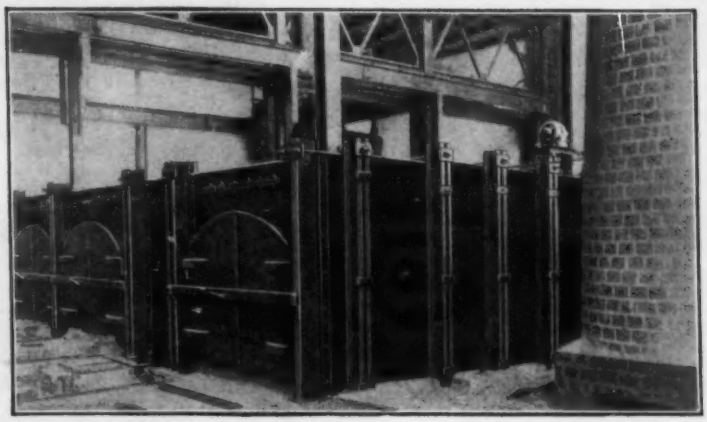

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8 classes of service

1. Fuel Surveys
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3. Complete Standardized Furnaces

4. Complete Furnace Designs
   We build you the furnace you need, furnishing Designs, Automatic Firing Equipment and Controls, Bills of Material, together with necessary Engineering and Erecting Supervision and Responsibility.
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Utilization Division of the Combustion Utilities Corporation

Output Jumps 33% with a 50% slash in fuel

A battery of furnaces were operating on a time cycle of 5 heats in 90 hours.

....then Surface Combustion Furnaces were installed.

The time cycle was increased to 8 heats in 97 hours.

....an approximate increase in production of 33 per cent.

And operating costs were slashed.

Tabulation shows a cut in the fuel bill of 50 per cent.

Read our newest bulletin. You'll find in it some facts that are worth thinking about. It will be ready for mailing in a few days—ask for it now.

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Branch Offices:

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Surface Combustion

WHEREVER *HEAT* IS USED IN INDUSTRY

When answering advertisements please mention "Transactions"

Swedish Nickel Alloy Carbonizing Boxes

SWEDISH NICKEL ALLOY

MOST ECONOMICAL AND EFFICIENT MATERIAL FOR

CARBONIZING BOXES
FURNACE TRAYS
MUFFLES and TUBES
BASKETS and RACKS
ANNEALING PANS
CONVEYOR PARTS, etc.

Swedish Crucible Steel Co.

Detroit, Mich.

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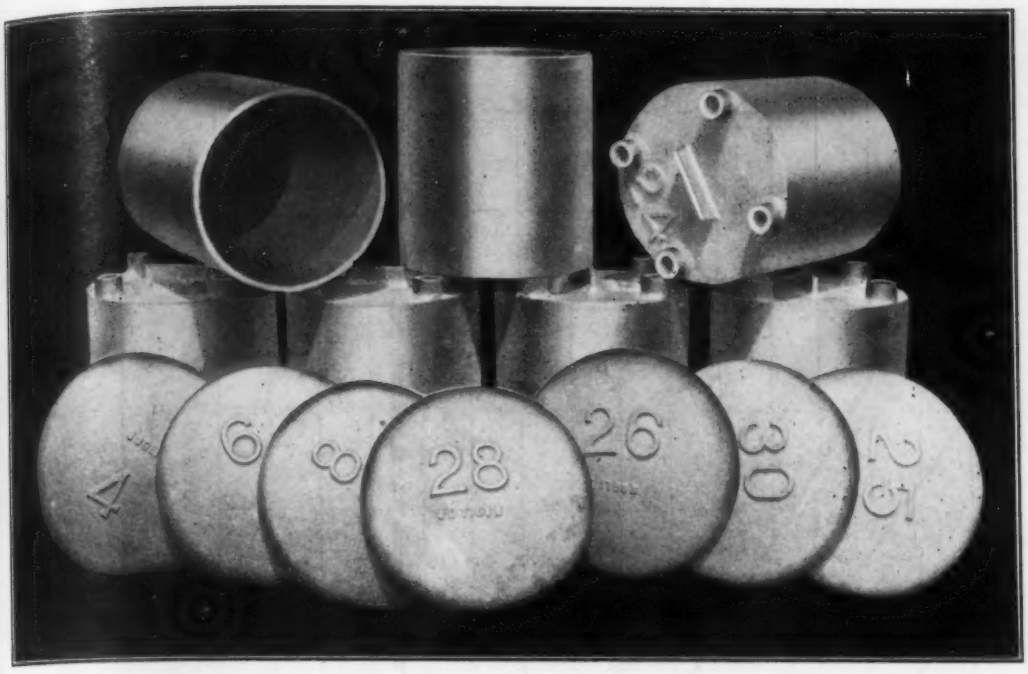

PART OF A SHIPMENT FOR

BROWN LIPE CHAPIN

OF

SWEDISH NICKEL ALLOY CARBONIZING BOXES

A high Nickel Chromium Alloy which will give

GOOD SERVICE

and the cost per heat hour will be HALF the cost of ANY OTHER BOX

Swedish Crucible Steel Co.

Detroit, Michigan

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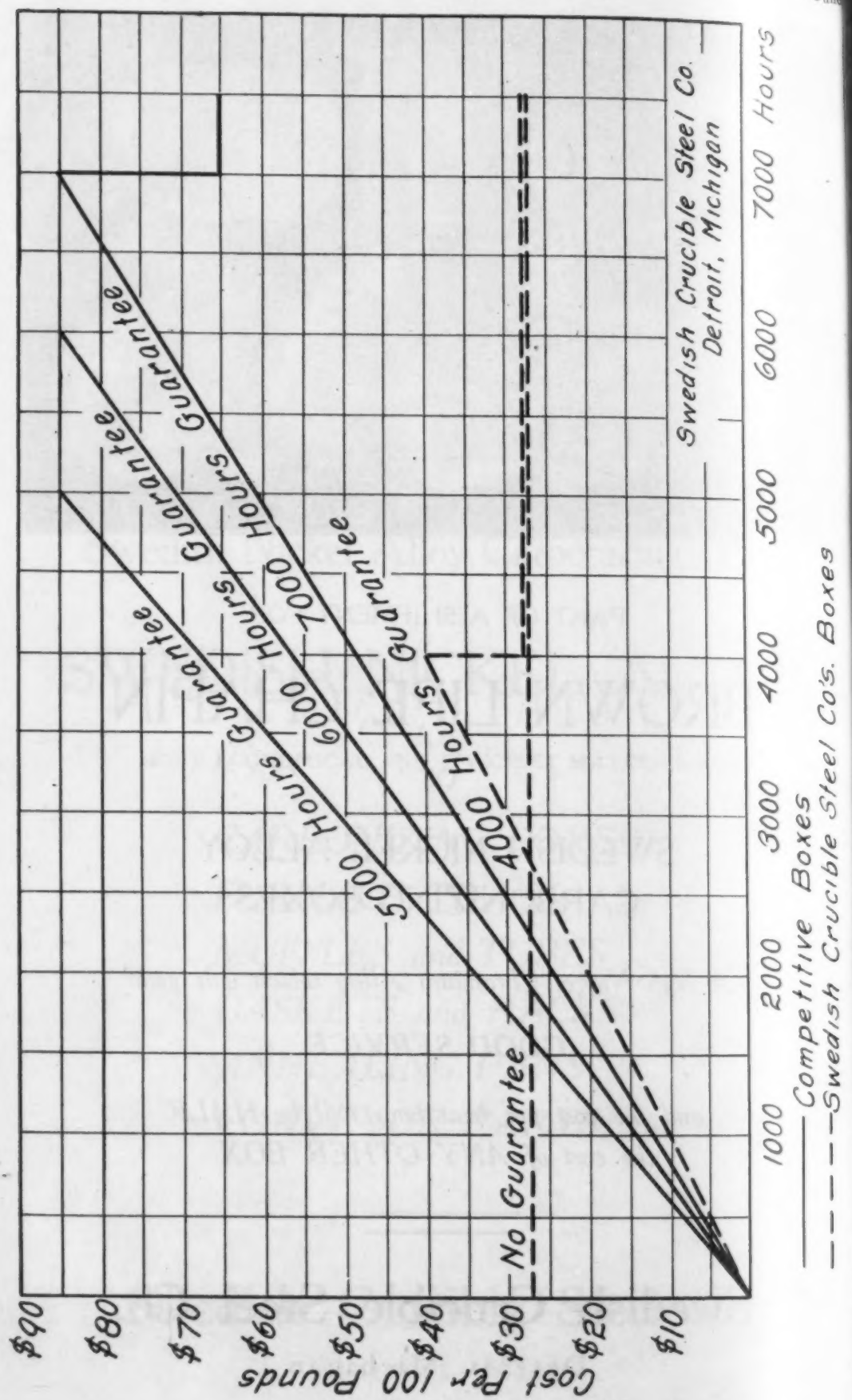
Swedish Crucible Steel Co.
Detroit, Michigan
7000 Hours Guarantee
6000 Hours Guarantee
5000 Hours Guarantee
4000 Hours
No Guarantee
1000 2000 3000 4000 5000 6000 7000 Hours
——Competitive Boxes
– – – –Swedish Crucible Steel Co's. Boxes
$90 $80 $70 $60 $50 $40 $30 $20 $10
Cost Per 100 Pounds

CHECK YOUR CARBONIZING BOX COSTS

Use the chart on the opposite page to check your box costs. Take the cost of the box you are now using. Say it weighs about 100 pounds. If so, you are probably paying $85.00 or more for it, if it is a high Nickel Chromium Alloy.

How about the guarantee? It is probably from 5000 to 6000 hours.

Understand the SCRAP clause thoroughly. There may be a nigger on the fence. Do you get paid for the scrap if the box fails before the guarantee has been fulfilled?

After determining all these factors draw your present cost line on the chart on the opposite page. With our NET COST line of 27½ cents per pound you will have no trouble seeing what a great saving you can make by the use of SWEDISH NICKEL ALLOY.

When an alloy box is sold with a high guarantee it is necessary for the vender to add enough to the selling price to make it possible for him to set up a reserve for rebates for unexpired service. This is especially necessary when boxes are guaranteed 6000 and 7000 hours.

As most heat treat plants use their boxes about 60 hours a week, a box must run over two years to fulfill a 6000 or 7000 hour guarantee. By that time the alloy vender may no longer be in business. You may get no rebate for unexpired service nor anything for the scrap.

If the vender is still in business you may have a show of getting back your rebate. Nevertheless you have given the alloy vender the use of your money—without interest—for the length of time the boxes were in service.

THINK IT OVER.

Swedish Crucible Steel Co.

Detroit, Michigan

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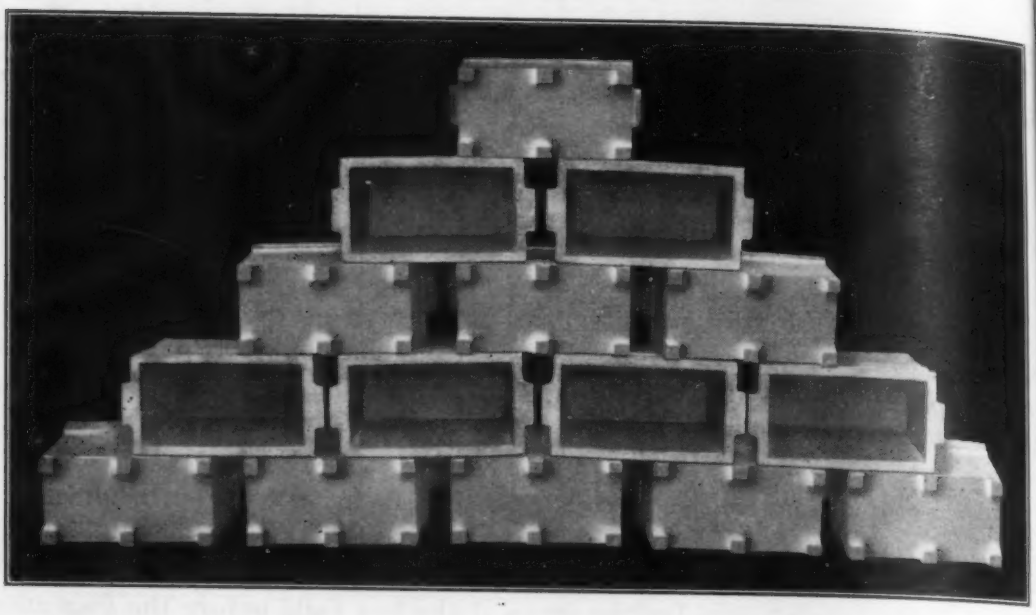
June ----Swedish Crucible Steel Co. Boxes



Partial Shipment of Swedish Nickel Alloy

for

PACKARD MOTOR CAR COMPANY

First Quality - - - Low Price

More Service

Swedish Crucible Steel Co.

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The latest and best of a long family of unabridged *Merriam*—Websters, each the recognized authority in its time. The One Supreme Authority: It is the standard of the Federal and State Courts and the Standard of the Government Printing Office. Contains 407,000 Vocabulary Terms; 6000 Illustrations; 2700 Pages. Buff Buckram Binding, $16.00.

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The following data sheets have been issued and sent to members. New members desiring back sheets may order all or any sheets desired at the "rate to members." Members will receive free data sheets as issued during the period of their membership.

Send all orders to A. S. S. T., 4600 PROSPECT AVE., CLEVELAND, O.

	Page No.	No. Sheets	Cost to Members	Cost to Non-Members
Nitrogen in Steel	A3-4	1	$0.05	$0.10
Melting Points of Chemical Elements / Fusing Points of Seger Cones	A5 / A6	1	.05	.10
Decimal and Metric Equivalents of Parts of an Inch	A7-10	2	.10	.20
Specific Heat of Air	A11-14	2	.10	.20
Weights of Steel Bars	A15-22	4	.20	.40
Temperature Conversion Table	A23 and 24	1	.05	.10
Iron Carbon Diagram	A25-38	7	.35	.70
Mass Influence in Heat Treatment	A39-42 Incl.	2	.10	.20
Nickel and Nickel-Chromium Steels	C3-24	11	.55	1.10
Stainless Steel	D3-10 Incl.	4	.20	.40
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In the manufacture of our various metals and alloys, we must use, and do use, the highest grade of ores, oxides and aluminum.

Tungsten Powder	97-98%	Pure Chromium	97-98%
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Ferro-Vanadium 35-40% (1% Silicon)

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Molybdenum

Chromium (Pure and Ferro), Manganese (Pure and Low C.), Cobalt, Silicon (Pure), Titanium, Silicon Aluminum Manganese Alloys (also with Ti.), Tungsten (Powder and Ferro), Ferro Aluminum, Calcium Silicon, Phosphor Copper and OTHER SPECIAL ALLOYS.

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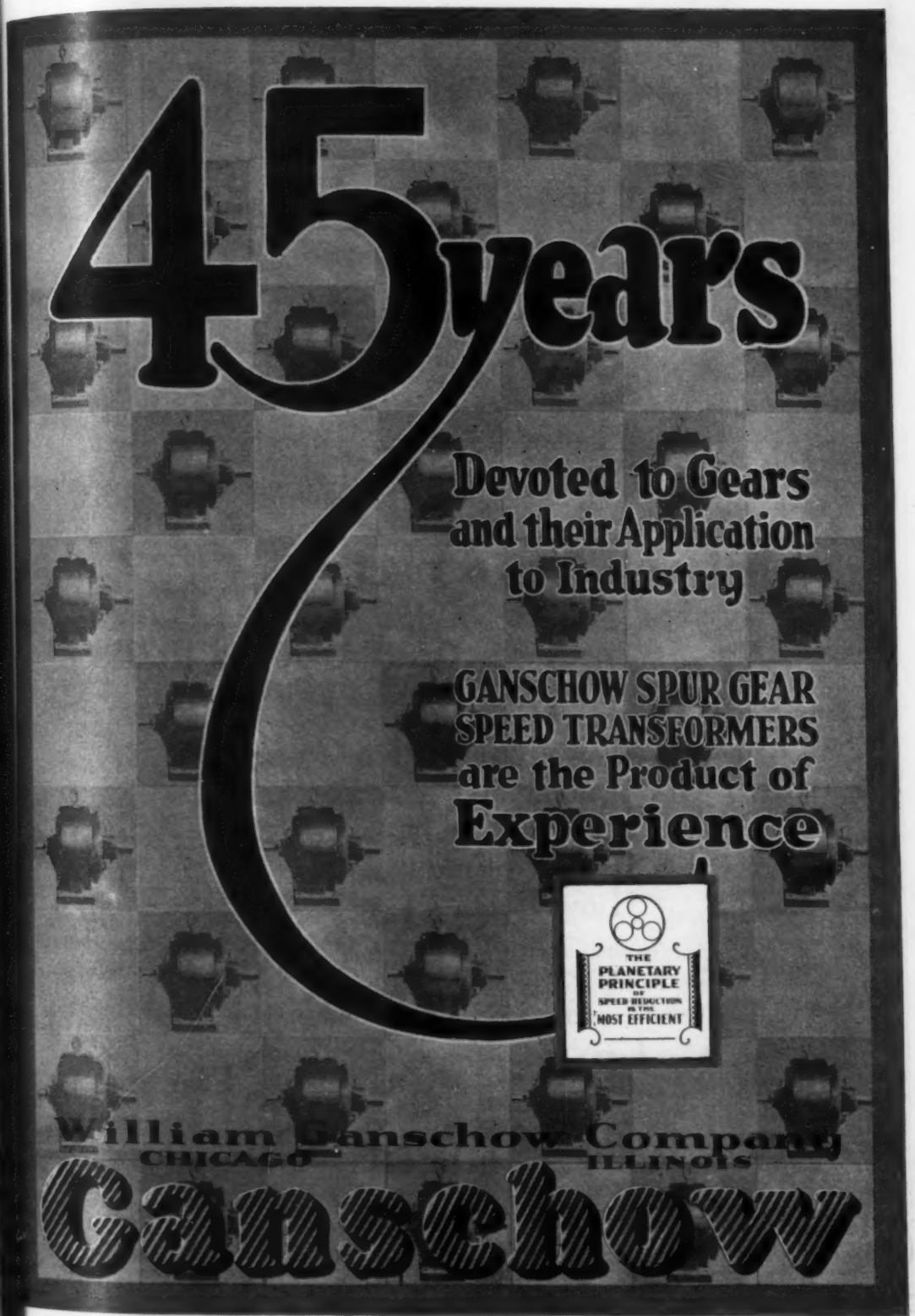
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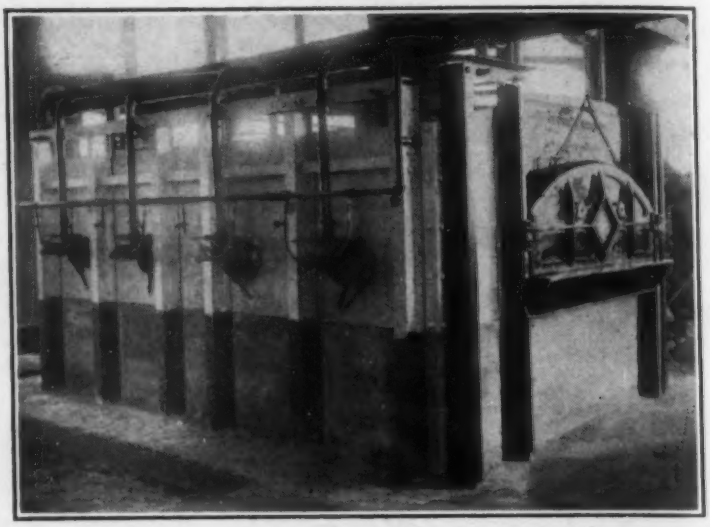

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What you can expect

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Low Operating Costs.
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Low Labor Costs.

You secure these essentials of Good Furnaces by specifying HAGAN

A furnace and a fuel for every Industrial Purpose

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ON the Kelly-Springfield Motor Truck, as on many other high grade motor trucks and automobiles, Chrome-Vanadium Steel is used for chassis springs.

"In the many years these springs have been in service," writes the Kelly-Springfield Motor Truck Company, Springfield, Ohio, "they have given a minimum amount of trouble and there has hardly been any breakage to speak of, regardless of the extreme overloading and severe service in which these trucks have been."

High in anti-fatigue and shock-resisting qualities and combining elasticity with strength, Vanadium Steel Springs are an asset to any motor truck or car.

Assuring spring satisfaction, Vanadium Steel Springs add life to the motor car or truck and free the owner from frequent spring breakage and replacements.

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for Strength, Toughness and Durability

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Why be bothered with the continual extra expense of re-sheeting your buildings — (labor and material) when you can sheet *once* with

DELHI Rustless Iron

and stop this leaking both in the building and in your pocket book.

Ask us for further data.

Black Or Galvanized Sheets
an Extreme But Nevertheless a Familiar Sight In Spite of Upkeep Costs

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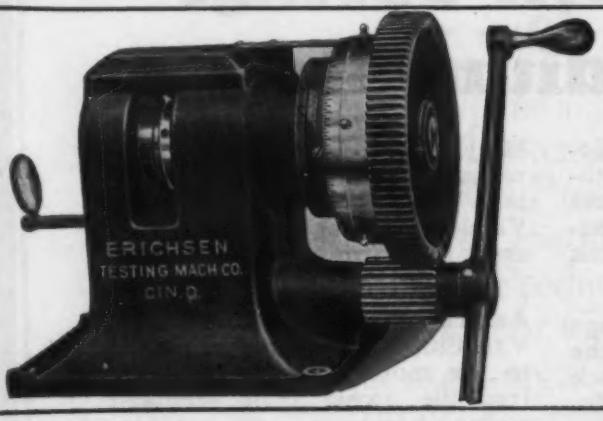

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Save time and save money.

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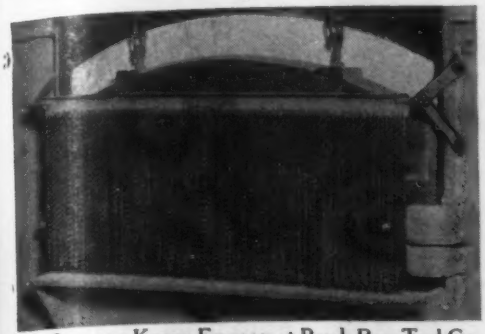
THE ECONOMY FURNACE CO. CHICOPEE, MASS.

Eliminate local overheating of container. Prevent the flame of combustion existing close to container. No salt can enter combustion chamber in the event of container failure. Zone of maximum heat input around side of container near top. Maximum container life.

Write for Salt Bath Furnace Bulletin K-7

THE ECONOMY FURNACE CO. CHICOPEE, MASS.



Chain Screen on Knapp Furnaces at Baash Ross Tool Co.

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Protect men from heat and glare, and furnace from chill. Save fuel, labor and "turnover." No interference with view, handling tools or charge. Before Hot Weather sets in write for bulletin.

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CARBURIZING COMPOUND

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Un-Breakable Tool Steel

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Industrial Furnaces

GENERAL FURNACE COMPANY

General Offices

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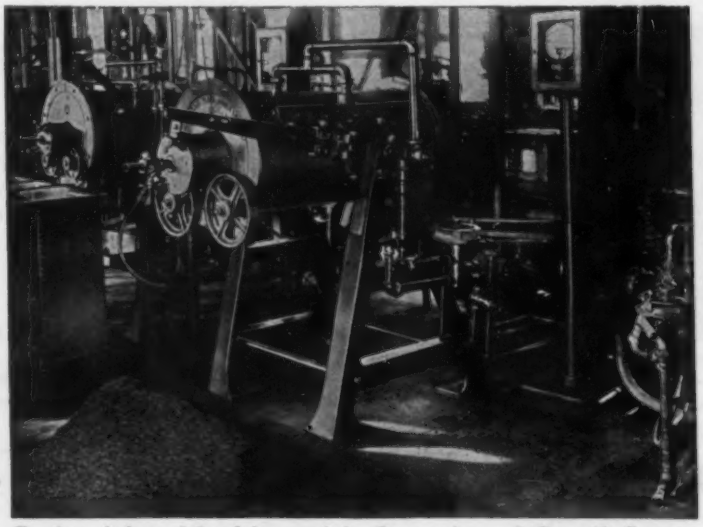

Carbonizing Machine with Quantity of Small Screw Pins Carbonized in Same

Results are QUICK — CERTAIN — ECONOMICAL

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These Oven Furnaces are made in more than 100 sizes

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Every Type of Gas Blast Burner, Furnace and Heating Machine for Industrial Uses

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R&H CHEMICALS AND SERVICE

will help you solve your problems in

SURFACE HARDENING

Choose any one of our

CYANIDE MIXTURES

(Strength 30%, 45% or 73/76% NACN)

for the best results, your selection being dictated by plant conditions.

❋

The Cheapest Method

if equipped to do so, is to make up your own bath as needed, using as a basis —

CYANEGG R&HCCo TRADE MARK

CYANIDE SODIUM 96/98%

guaranteed 51/52% cyanogen
strength equal to 128/130% KCN

Dilute with Soda Ash and Salt, to suit.

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Our mixtures are also highly suitable for reheating after pack hardening

Better heating medium than lead — prevent oxidation

[Technical assistance rendered without charge]

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(*Completed with the June, 1925, issue, 6 numbers*)

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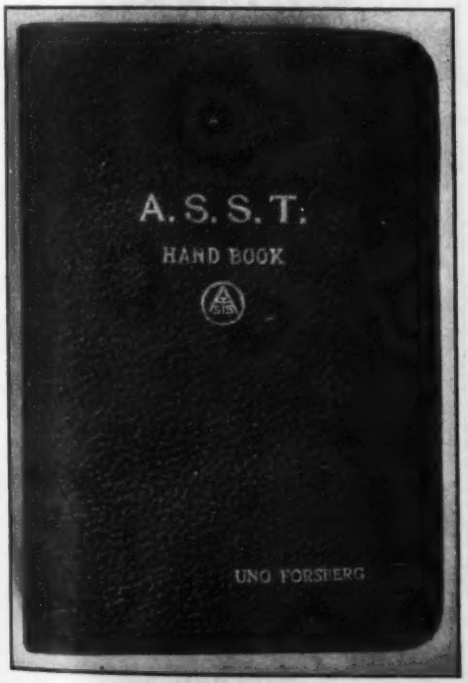

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BARS SHEETS
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STAINLESS STEEL
BARS SHEETS

For Reclaiming Carburizing Compound

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Takes out scale, slag, clay, sand, etc., and confines dust.
Saves 75% Labor cost.
Reclaims 25% more Compound.
Direct connected Motor if desired.

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Made from the best ores the world produces

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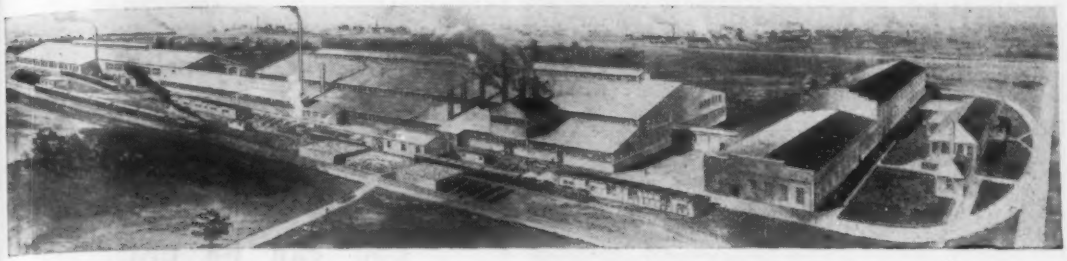

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Since then Fahrite has sold itself and has served hundreds of applications in temperatures up to 2000° F. The increased demand is the best evidence of its success.

The most improved facilities and a skilled organization of practical foundrymen are producing better Fahrite castings than ever before.

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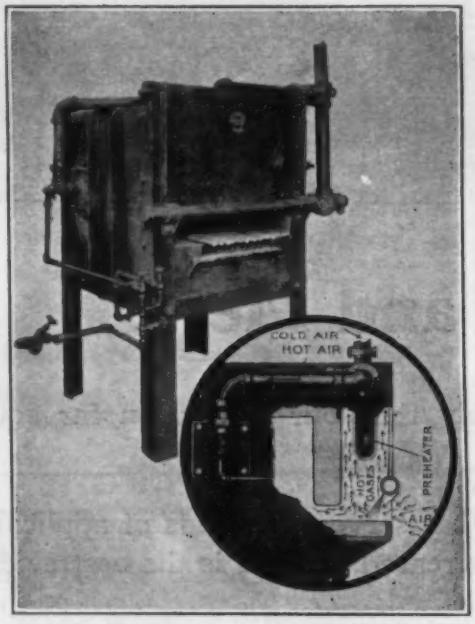
Forge Shop Comfort
In Summer

When your forgemen knock off work in summer, **don't blame the loss of production and profits on the weather.**



Patented

Section showing deflection of hot gases by downward blast, **with induced air toward the forge,** and construction for preheating air and protecting operator.

Most likely your men balk at the discomfort caused by the terrific heat, smoke and gases given off by obsolete forges.

You can be practically immune to summer layoffs and losses by equipping your forge shop with

ROCKWELL ECONOMIZER FORGES

A novel arrangement of downward blast over the working opening prevents the escape of heat, smoke and gases into the face of the heater and creates a current of cool, refreshing air past him and *toward* the forge.

The hot gases from the Rockwell Forge are utilized to preheat the air for combustion.

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Are the Cure for "Spring Fever" in the Forge Shop

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Write for free copy to our nearest office.

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MADE BY THE
CRUCIBLE PROCESS

CLARITE HIGH SPEED STEEL
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It pays to use Good Tool Steel.

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Heppenstall Forge & Knife Co.

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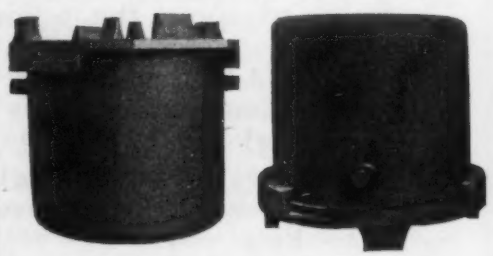
Oct. 12, 1915
CARBURIZING BOXES
"The Cost Cutting Box"



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The Original Inverted Box.
Retention of Gases Builds Pressure and Gives Deeper and More Uniform Penetration.
Saves Material and Prevents Scaling and Oxidation.
No Claying or Screening.
Gives Equal Depth of Case in Less Time.
Every Layer Carburized Uniformly.

YOU "WIL-CAN" OTHER TYPES AFTER A TRIAL

CANNON-STEIN STEEL CORP.

Trade *"Rita"* Mark
BRAND STEELS
Syracuse — **New York**

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Is Now Done Almost Exclusively With

The SCLEROSCOPE

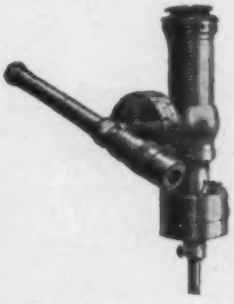
[International Standard]

Direct reading, can be operated by anyone with great rapidity. Measures softest metals and hardest steels without adjustment. Send for our booklet, free.

The PYROSCOPE

as a heat indicator, has solved the most difficult problems.

In heat treatment of steel, forging, founding, etc. Unexcelled for constancy, inexpensive.



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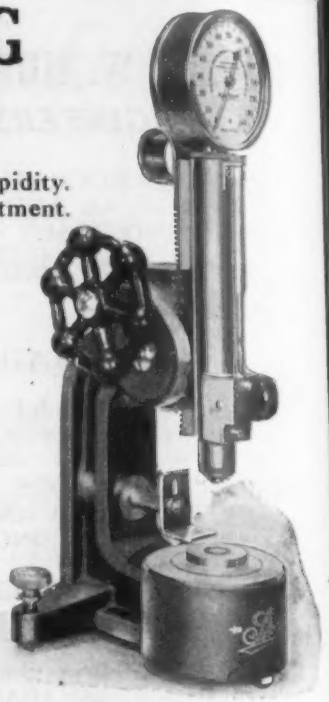

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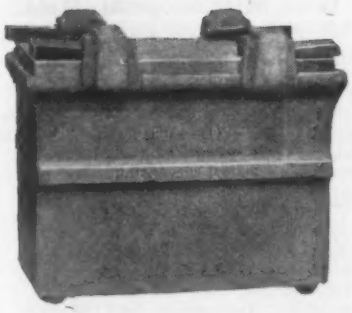

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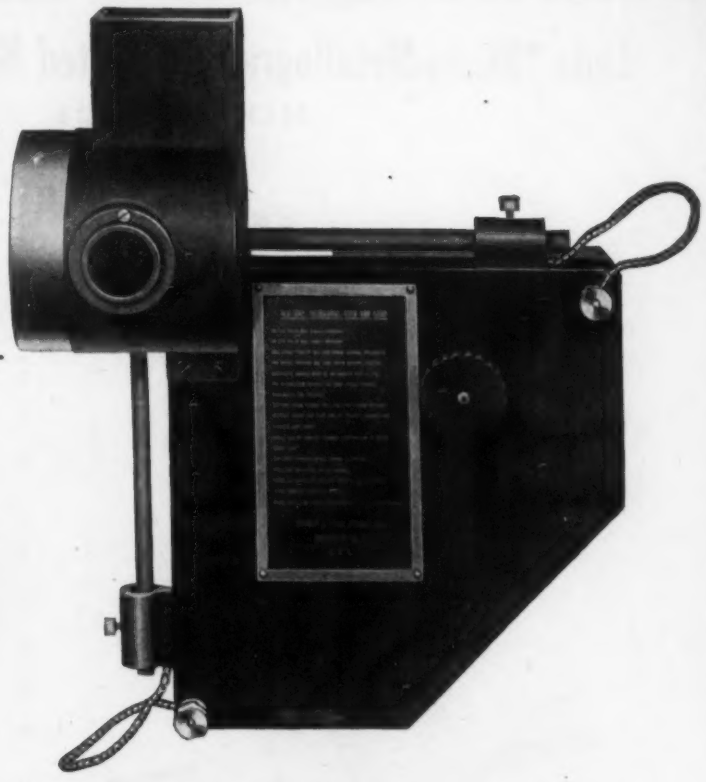

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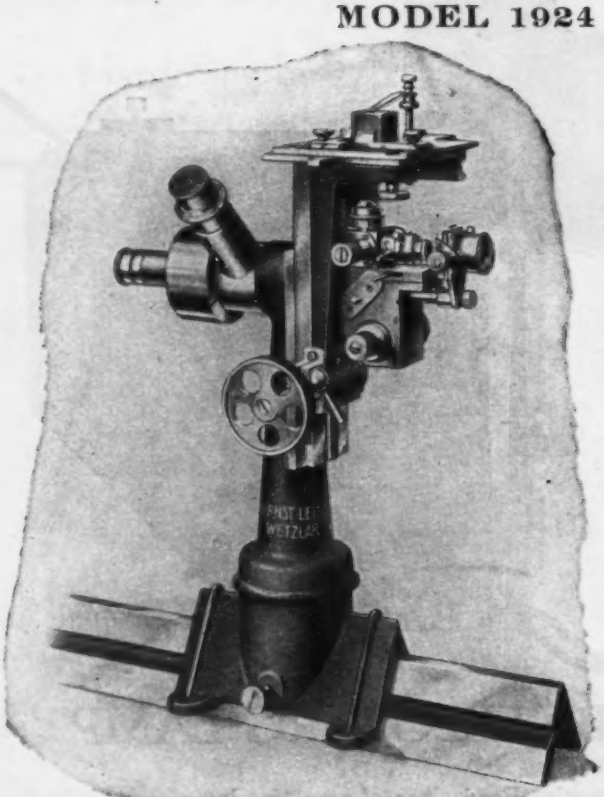

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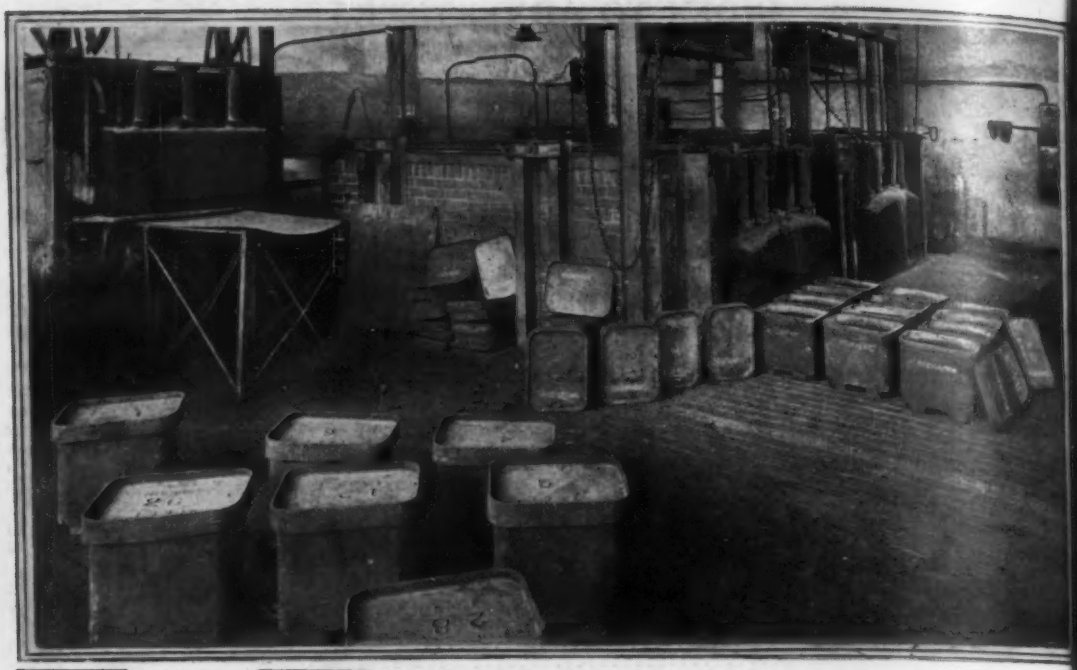

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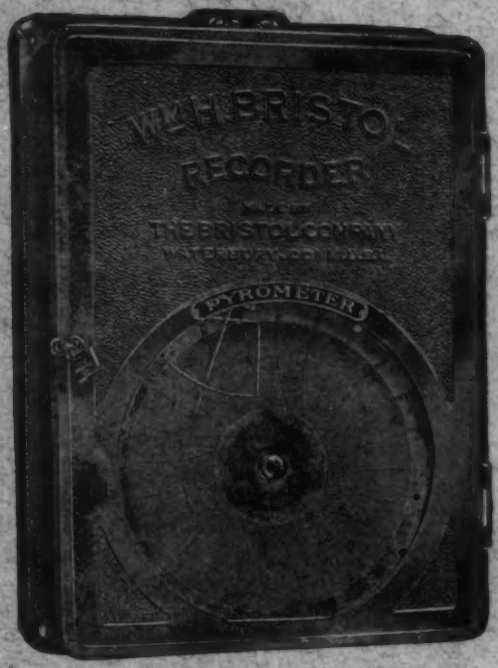

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